A FRAMEWORK FOR THE INVOLVEMENT OF THE MAINTENANCE MANAGER DURING THE DESIGN DEVELOPMENT AND REVIEW STAGES

BY

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IN THE NAME OF ALLAH, THE MOST GRACIOUS AND THE MOST MERCIFUL

DEDICATION

I dedicate this work to My Precious

Parents,

Wife, Sons and Daughter,

Sisters,

Whose patience, continuous prayers and perseverance led to this accomplishment

ACKNOWLEDGEMENT

All praise and thanks are due to Almighty Allah, Most Gracious and Most Merciful, for his immense beneficence and blessings. He bestowed upon me health, knowledge and patience to complete this work. May peace and blessings be upon prophet Muhammad (PBUH), his family and his companions.

Thereafter, acknowledgement is due to KFUPM for the support extended towards my research through its remarkable facilities and for granting me the opportunity to pursue graduate studies. My sincere appreciation and prayers are due to all those experts and professionals who referenced in this study and those who have filled and returned the study questionnaire forms.

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Finally, I have tried my best to avoid any mistakes or inaccurate data and information in this study. I apologize for any mistake that was beyond my understanding and knowledge, and may ALLAH forgive me.

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THESIS ABSTRACT

Name	:	FADI ABDULRAZAQ A. FATAYER
Title	:	**A Framework for the Involvement of the Maintenance Manager during the Design Development and Review Stages**
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Virtually, there exists no feedback between the maintenance manager and the integrated design team. Such feedback, if provided, would result in reducing the challenges that are attributed to faulty design, and faced by the maintenance manager during the operation and maintenance phase. This research aims at (1) identifying and assessing the most significant operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during the design development and review stages, (2) Identifying and assessing the major concerns and/or details raised by the maintenance manager at different design stages, (3) investigating the current practices of the maintenance manager's involvement, and (4) developing a framework to prioritize the major concerns and /or details raised by the maintenance manager during the design development and review stages at the most significant project design phase. A series of sixty six operation and maintenance problems and eighty five major concerns and/or details for different design disciplines were identified depending on literature review and interviews with the directors of maintenance department divisions of two universities namely, King Fahd University of Petroleum and Minerals and Dammam University. The operations and maintenance problems and the major concerns were assessed, and the current practices of maintenance manager's involvement were captured through developing; testing and administering a questionnaire survey to the maintenance departments of thirteen public Saudi Arabian universities. The findings confirmed the importance of the identified problems and concerns, where all problems and concerns were assessed as either "extremely important", "very important" or "important". After the analysis of the questionnaire survey, 60% of project design stage was determined to be the most significant project design stage. This stage necessitated the identification of forty three major concerns. The framework was developed based on these concerns. It required developing a scoring matrix and performing a pair-wise comparison for each of the concern by three experts. The power method applied to Eigen-value method was used to check consistency of data analysis. The 't' test using spearman (roh) correlation was applied to investigate the correlation between the experts and directors of maintenance divisions who ranked the forty three concerns.

بسم الله الرحمن الرحيم

خلاصة الرسالة

اسم الطالب الكامل : فادي عبدالرزاق عبدالغني فطاير

عنوان الرسالة : إطار إشراك مسؤول الصيانة خلال مراحل تطوير ومراجعة التصاميم

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عمليا، لا يوجد هنالك أي تبادل للأراء ووجهات النظر بين مسؤول الصيانة وفريق التصميم المتكامل. مثل هذا التبادل، اذا تم، سوف يكون له عظيم الأثر في الحد من التحديات التي تعزى الى التصميم الخاطىء والذي يواجه من قبل مسؤول الصيانة خلال مرحلة التشغيل والصيانة. يهدف هذا البحث الى (1) : تحديد وتقييم أهم مشاكل مرحلة التشغيل و الصيانة والتي تظهر كنتيجة لعدم إشراك مسؤول الصيانة خلال مراحل تطوير ومراجعة التصاميم، (2) تحديد وتقييم مجموعة الاهتمامات و / أو التفاصيل التي يثيرها مسوؤل الصيانة أثناء مراحل البناء المختلفة، (3) بحث الممارسات المتبعة بالوقت الحالي في إشراك مسؤول الصيانة و (4) إنشاء إطار لتحديد أولوية الاهتمامات و / أو التفاصيل التي يثيرها مسوؤل الصيانة أثناء مراحل تطوير ومراجعة التصاميم عند مرحلة تصميم المشروع الأكثر أهمية. وقد تم تحديد 66 من مشاكل التشغيل والصيانة و85 من الاهتمامات الرئيسية و / أو التفاصيل لمختلف تخصصات التصميم اعتمادا على مراجعة واستعراض الأدب والمقابلات مع مديري شعب قسم الصيانة من جامعتين هما جامعة الملك فهد للبترول والمعادن و جامعة الدمام. لقد قيّمت مشاكل التشغيل والصيانة و الاهتمامات الرئيسية و / أو تفاصيل، ولوحظت الممارسات المتبعة بالوقت الحالي في إشراك مسؤول الصيانة من خلال انشاء، فحص وتوزيع إستبيان على أقسام الصيانة في 13 جامعة سعودية حكومية. أكد الأستبيان على أهمية المشاكل والأهتمامات المحددة، حيث أن النتائج أكدت أهمية جميع المشاكل والأهتمامات المعرفة حيث أن جميع المشاكل والأهتمامات قيمت إما "مهم جدا بقوة"، "مهم جدا"، أو "مهم". بعد أن تم تحليل الأستبيان، حددت مرحلة 60% من تصميم المشروع على أنها أكثر مرحلة مهمة في تصميم المشروع. اقتضت هذه المرحلة تحديد 43 إهتمام من الاهتمامات الرئيسية. لقد أنشأ الأطار بناءا على هذة الأهتمامات . يتطلب هذا الأطار انشاء مصفوفة بيانات و إجراء مقارنات زوجية حكيمة لكل اهتمام من الاهتمامات من قبل ثلاث خبراء مختلفين. لقد استخدم مبدا القوة المطبق الى مبدأ القوة الذاتية من اجل التأكد من اتساق تحليل البيانات. لقد طبّق اختبار تي- تست باستخدام عامل توافق سبيرمان من أجل فحص مدى التوافق بين الخبراء ومديري شعب الصيانة الذين قاموا بتقيم هذه الأهتمامات الثلاثة والأربعون.

درجة الماجستير في العلوم
جامعة الملك فهد للبترول والمعادن
الظهران ، المملكة العربية السعودية
مارس 2012م

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Maintenance is defined as "a combination of any actions carried out to retain an item in, or restore it to, an acceptable condition" (BS3811, 1964; Aris, 2006). Also, Maintenance can be defined as the orderly control of activities required to keep a facility in an as-built condition, with the ability to maintain its original productive capacity (Bagadia, 2006).

Maintenance is a sub-set of the many functions within the professional field of facilities management. It comprises a series of activities aiming at minimizing or eliminating the incidences of failures, ensuring satisfactory levels of operation, and prolonging the useful life of buildings (Moller and McCartney, 2007). The maintenance manger is the person responsible for the operation and maintenance phase during the life cycle of facilities. He should enjoy leadership character in order to manage multi disciplinary teams. He should also possess the necessary technical, analytical, and interpersonal skills for rational decision-making.

Planning for the maintenance should start during the design phase and continue throughout the useful life of the building. Previous research indicated that the decisions made during the planning and design development phases have an impact on the future performance of the building. The maintenance manager should be consulted during the design development and review stages. The feedback provided from the maintenance manger to the integrated design team serves to avoid the repetition of frequent and costly operation and maintenance problems that occur during the useful life of buildings (Aris, 2006).

1.2 STATEMENT OF THE PROBLEM

Nowadays, maintenance managers are faced with a multitude of frequent and costly building performance problems during the operation and maintenance phase. Previous research indicate that the majority of these problems are attributed to the decisions made during the design development and review stages (Al-Hammad et al. 1997; Low and Chong, 2004; Ramly ,2006; Aris, 2006). Therefore, there is a need to identify and assess the most significant operation and maintenance problems that commonly emerge as a consequence of the maintenance manager’s lack of involvement.

Further, several studies have stressed on the significance and the benefits of involving the maintenance manager with the integrated design team during the design development and review stages (Arditi and Nawakorawit, 1999a; Dunston and Williamson, 1999; Somorova, 2007; Mohammed and Hassanain, 2010). Such involvement would result in reducing the challenges that are attributed to faulty design. Nevertheless, a review of the state-of-the-art literature in the domain of building maintenance management revealed the non-availability of a detailed investigation pertaining to the timing, procedure as well as the extent of the involvement of the maintenance manager during the early design phase.

Therefore, there is a need to investigate the current practices of the maintenance manager's involvement.

Moreover, there is a need to develop a framework for the involvement of maintenance manager during the design development and review stages of building projects. Development of the framework necessities the identification and assessment of the major concerns and/or details raised by the maintenance manager during the design development and review stages which will have significant impacts on building maintainability in the future.

1.3 OBJECTIVES OF THE STUDY

The objectives of this research are as follows

1- To identify and assess the most significant operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during the design development and review stages.

2- To identify and assess the major concerns and/or details raised by the maintenance manager during the design development and review stages which will have significant impacts on building maintainability in the future.

3- To investigate the current practices of the maintenance manager's involvement during the design development and review stages.

4- To develop a framework to prioritize the major concerns and /or details raised by the maintenance manager during the design development and review stages at the most significant project design stage.

1.4 SCOPE AND LIMITATIONS

The scope and limitations of this research are as follows:

1- The interviews for identifying the operation and maintenance problems that emerges as a consequence of the decisions made during the design phase will be conducted with the engineers of the operation and maintenance departments at two universities, namely King Fahd University of Petroleum and Minerals, and Dammam University.

2- The pilot-testing of the developed questionnaire survey will carried out through consultations with the engineers of the operation and maintenance departments at two universities, namely King Fahd University of Petroleum and Minerals, and Dammam University.

3- Responses to the developed questionnaire surveys will be obtained from the maintenance departments of thirteen public Saudi Arabian universities namely:

- Umm Al-Qura University
- King Abdul Aziz University
- King Fahd University of Petroleum and Minerals
- Dammam University
- King Saud University
- King Khalid University
- Imam Muhammad bin Saud Islamic University
- Taif University
- King Faisal University
- Qasim University

- Islamic University of Al-Madinah Al-Munawarah
- Taibah University
- Najran University

1.5 SIGNIFICANCE OF STUDY

The significance of this research stems from the following:

1- This study has the potential to raise awareness among the built-environment community in Saudi Arabia about the interaction as well as the communication between the maintenance manager and the integrated design team throughout the design phase. This is achieved through identifying and documenting the current practices of involving the maintenance manager with the integrated design team during the design development and review stages.

2- The involvement of maintenance manager during the design development and review stages will reduce the amount as well as the complexities of unplanned maintenance activities in buildings.

3- This study aims at investigating the most important operation and maintenance problems that face maintenance managers during the operation phase of building projects; and the remedial set of concerns and/or details. This serves two purposes. The first is for design professionals to avoid the repetition of faulty design defects that results in frequently and costly operation and maintenance problems. The second is for maintenance managers to manage easily maintainable projects in the future.

1.6 RESEARCH METHODOLOGY

This section presents the research activities through which each objective will be achieved.

1.6.1 The first objective

The first objective of this study is to identify and assess the most significant operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during the design development and review stages. This objective will be achieved through the following phases:

Phase I: Operation and maintenance problems identification: the research activities planned to achieve this phase include:

a) Reviewing the state-of-the-art literature in the field of building defects and maintenance to identify the common operation and maintenance problems that are attributed to the lack of the maintenance manager's involvement during the design development and review stages.

b) Interviewing the directors of the maintenance departments' divisions [architectural, structural, electrical, mechanical and heating, ventilating and air conditioning (HVAC)] at two universities for the purpose of identifying the common operation and maintenance problems – in the above listed professional areas of practice - that are attributed to the lack of the maintenance manager's involvement during the design development and review stages.

<u>Phase II: Operation and maintenance problems assessment:</u> the research activities planned to achieve this phase include:

a) Developing a questionnaire survey to assess the identified operation and maintenance problems.

- Part I of the questionnaire survey (appendix-A) consists of five sections. These sections should be completed by the directors of the following maintenance department's divisions: architectural, structural, electrical, mechanical, and HVAC. Each section consists of two sub-sections as follows:
  - ✓ **A**: This sub-section requires respondents to provide general information, the number of years of experience in working at the maintenance department, as well as to indicate their wish to receive a summary of the findings of the study.
  - ✓ **B**: This sub-section contains the respondents assessment for:
    - o B1: The identified operations and maintenance problems that commonly emerge as a consequence of maintenance manger's lack of involvement during the architectural, structural, electrical, mechanical and HVAC design development and review stages.
    - o B2: It is related to the second objective of the study as will be discussed in Section 1.6.2.

- The respondent will be asked to rate the degree of importance of each of the identified operation and maintenance problems by selecting one of the following evaluation terms: “Extremely Important” with 4 points, “Very Important” with 3 points, “Important” with 2 points, “Somewhat Important” with one point and “Not Important” with zero points.

b) Pilot-testing the developed questionnaire survey through consultations with the directors of the maintenance departments’ divisions [architectural, structural, electrical, mechanical and heating, ventilating and air conditioning (HVAC)] at two universities, namely King Fahd University of Petroleum and Minerals, and Dammam University.

c) Distributing the pilot-tested questionnaire survey to thirteen (13) public Saudi Arabian universities that have substantial infrastructure.

<u>Phase III: Data Analysis:</u> This phase describe the method that will be used to analyze the data received from the respondents to part I of the questionnaire survey. The rank for each operation and maintenance problem depends on the corresponding value of the importance index. The value of the importance index will be calculated using the following equation (Dominowski, 1980):

$$\text{Importance Index (I)} = \frac{\sum_{i=0}^{4} a_i x_i}{4\sum_{i=0}^{4} x_i} \times 100\%$$

Where:

i = Response category index where i= 0,1, 2, 3, 4

ai = Wight given to i response where i= 0, 1, 2, 3, 4

xi = variable expressing the frequency of i as illustrated in the following:

- ✓ $\mathbf{x_0}$ = frequency of **“Extremely Important”** response corresponding to a0 = **4**.
- ✓ $\mathbf{x_1}$ = frequency of **“Very Important”** response corresponding to a1 = **3**.
- ✓ $\mathbf{x_2}$ = frequency of **“Important”** response corresponding to a2 = **2**.
- ✓ $\mathbf{x_3}$= frequency of **“Somewhat Important”** response corresponding to a3 = **1**.
- ✓ $\mathbf{x_4}$ = frequency of **“Not Important”** response corresponding to a4 = **0**.

To reflect the scale of the respondents’ answers to the questionnaire, the importance index is classified according to the following scale (Juaim and Hassanain, 2011), as illustrated in Table 1-1. The findings of this objective will be presented in chapter five. Figure 1.1 illustrates the research methodology for the first objective # 1.

Table 1-1: The importance index rate and classifications (Juaim and Hassanain, 2011)

Importance Index	**Classification**
0 – <12.5%	Not Important
12.5 – <37.5%	Somewhat Important
37.5 – <62.5%	Important
62.5 – <87.5%	Very Important
87.5 – 100%	Extremely Important

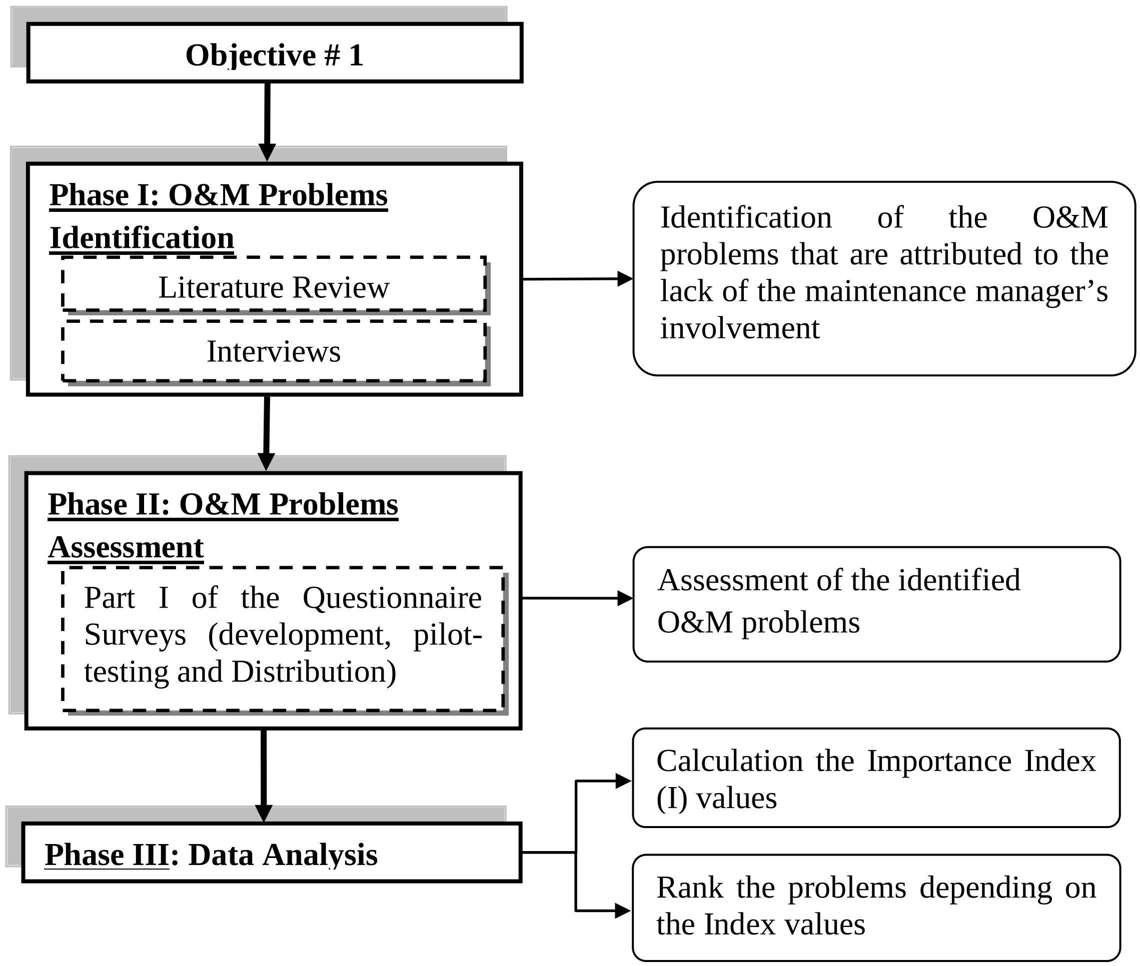

Figure 1.1: Research methodology for objective #1

1.6.2 The second objective

The second objective is to identify and assess the major concerns and/or details raised by the maintenance manager during the design development and review stages which will have significant impacts on building maintainability in the future. This objective will be achieved through the following phases:

<u>Phase I: Set of concerns and/or details identification</u>: the research activities planned to achieve this phase include:

a) Reviewing the state-of-the-art literature for the purposes of understanding the working mechanisms of technical building systems.

b) Interviewing the directors of the maintenance departments' divisions [architectural, structural, electrical, mechanical and heating, ventilating and air conditioning (HVAC)] at two universities for the purpose of identifying the set of concerns and/or details – in the above listed professional areas of practice – which will have significant impacts on building maintainability in the future.

c) Compiling a list of remedial set of concerns and/or details for the identified operation and maintenance problems.

<u>Phase II: Set of concerns and/or details assessment:</u> the research activities planned to achieve this phase include:

a) Developing a questionnaire survey to assess the identified set of concerns and/or details.

   - Part I of the questionnaire survey (appendix-A) consists of five sections. These sections should be completed by the directors of the following maintenance department's divisions: architectural, structural, electrical, mechanical, and HVAC. Each section consists of two sub-sections as follows:

     ✓ **A**: This sub-section requires respondents to provide general information, the number of years of experience in working at the maintenance department, as well as to indicate their wish to receive a summary of the findings of the study

- ✓ **B**: This sub-section contains the respondents assessment for:
  - **B1**: It is related to the first objective of the study as discussed in Section **1.6.1.**
  - **B2:** The identified major concerns and/or details that raised by the maintenance manager during the architectural, structural, electrical, mechanical, and HVAC design development and review stages at different project design stages (i.e. 30%, 60%, and 90%).

- The respondent will be asked to rate the degree of importance of each of the identified set of concerns and/or details by selecting one of the following evaluation terms: “Extremely Important” with 4 points, “Very Important” with 3 points, “Important” with 2 points, “Somewhat Important” with one point and “Not Important” with zero points.

b) Pilot-testing the developed questionnaire survey through consultations with the directors of the maintenance departments’ divisions [architectural, structural, electrical, mechanical and heating, ventilating and air conditioning (HVAC)] at two universities, namely King Fahd University of Petroleum and Minerals, and Dammam University.

c) Distributing the pilot-tested questionnaire survey to thirteen (13) public Saudi Arabian universities that have substantial infrastructure

<u>Phase III: Data Analysis</u>: this phase describe the method that will be used to analyze the data received from the respondents to part I of the questionnaire survey. The rank for each set of concerns and/or details depends on the corresponding value of the importance index. The value of the importance index will be calculated using the following equation (Dominowski, 1980):

$$\text{Importance Index (I)} = \frac{\sum_{i=0}^{4} a_i x_i}{4\sum_{i=0}^{4} x_i} \times 100\%$$

Where:

i = Response category index where i= 0,1, 2, 3, 4

ai = Wight given to i response where i= 0, 1, 2, 3, 4

xi = variable expressing the frequency of i as illustrated in the following:

- ✓ $\mathbf{x_0}$ = frequency of **“Extremely Important”** response corresponding to a0 = **4**.
- ✓ $\mathbf{x_1}$ = frequency of **“Very Important”** response corresponding to a1 = **3**.
- ✓ $\mathbf{x_2}$ = frequency of **“Important”** response corresponding to a2 = **2**.
- ✓ $\mathbf{x_3}$= frequency of **“Somewhat Important”** response corresponding to a3 = **1**.
- ✓ $\mathbf{x_4}$ = frequency of **“Not Important”** response corresponding to a4 = **0**.

To reflect the scale of the respondents’ answers to the questionnaire survey, the importance index is classified according to the scale as illustrated in Table 1-1 (Juaim and Hassanain, 2011), The findings of this objective will be presented in chapter five. Figure 1.2 illustrates the research methodology for the first objective # 2

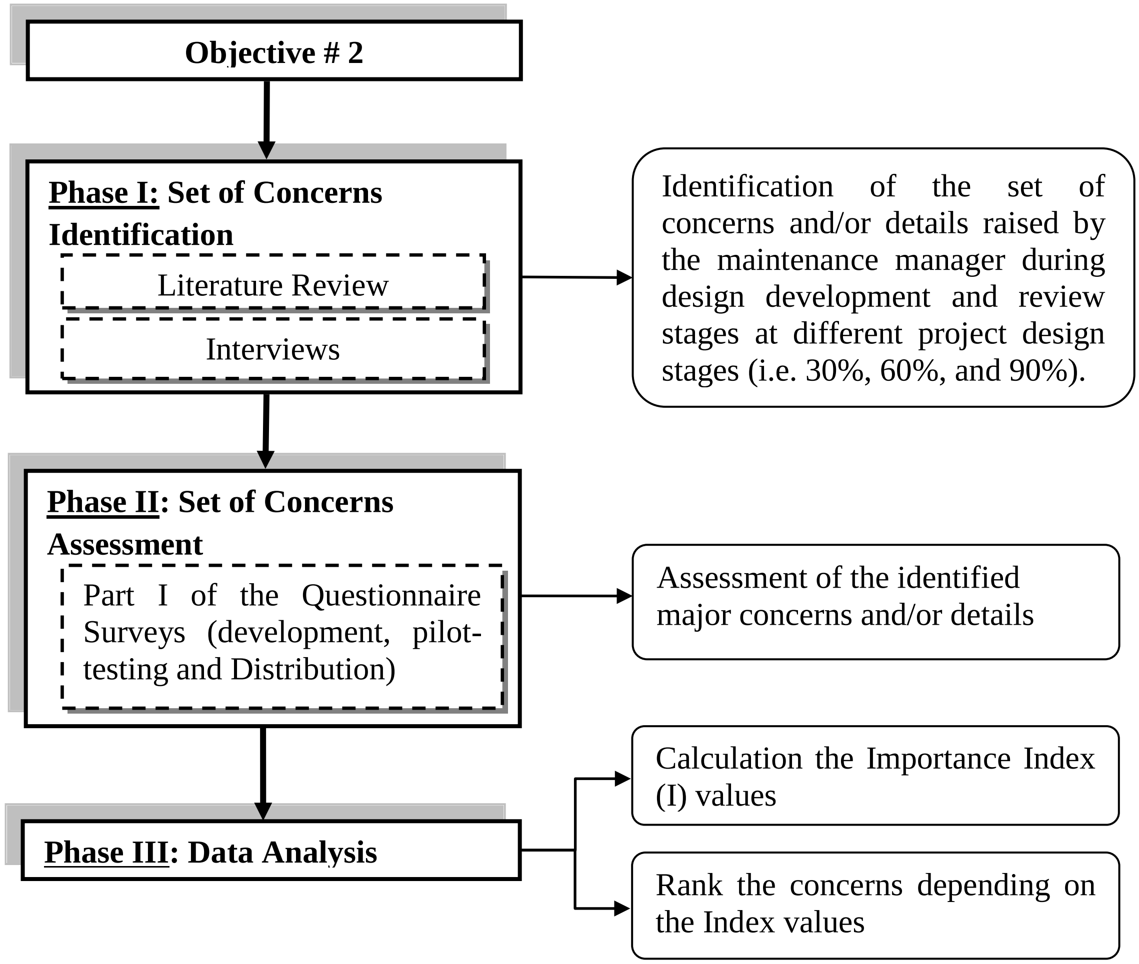

Figure 1.2: Research methodology for objective #2

1.6.3 The third objective

The third objective of the study is to examine the current practices of the maintenance manager's involvement during the design development and review stages. This objective will be achieved through the following phases:

<u>Phase I: Understanding the Involvement procedure:</u> the research activities planned to achieve this phase include:

a) Reviewing the state-of-the art literature for the purposes of addressing the significance of involving the maintenance manger during the design development and review stages and reviewing previous studies that describe the challenges to the process of providing feedback from the operation stage to the design development and review stages.

b) Interviewing the directors of the maintenance departments' divisions [architectural, structural, electrical, mechanical and heating, ventilating and air conditioning (HVAC)] at two universities for the purpose of identifying the current procedure and the timing of involving the maintenance managers in the process of reviewing and providing feedback during the design development and review stages.

Phase II: Aspects of the current practice: the research activities planned to achieve this phase include:

a) Developing a questionnaire survey in order to identifying the aspect of the current practices of the maintenance manager's involvement during the design development and review stages.

- Part II of the questionnaire survey (Appendix-A) aims at identifying these practices of the maintenance manager's involvement specifically, the timing, procedure as well as the extent of the maintenance manager's involvement during the design development and review stages. This part consists of two sections; the two sections should be completed by the maintenance division's managers of public Saudi Arabian universities. These two sections are as follows:

- ✓ **A:** This section contains four general questions about the respondent's name, contact information, number of years that the building stock has been in operation his experience as well as if interested in receiving a summary of the finding of the study.
- ✓ **B:** This section contains ten different questions on the current practice of the maintenance manager's involvement during the design development and review stages.

b) Pilot-testing the developed questionnaire survey through consultations with the directors of the maintenance departments' divisions [architectural, structural, electrical, mechanical and heating, ventilating and air conditioning (HVAC)] at two universities, namely King Fahd University of Petroleum and Minerals, and Dammam University.

c) Distributing the pilot-tested questionnaire survey to thirteen (13) public Saudi Arabian universities that have substantial infrastructure.

Phase-III: Data analysis: The results of part II of the questionnaire survey will be analyzed using simple descriptive statistical techniques including graphics, percentages and summaries of the findings. The findings will be presented in chapter six. Figure 1.3 illustrates the research methodology for the first objective # 3.

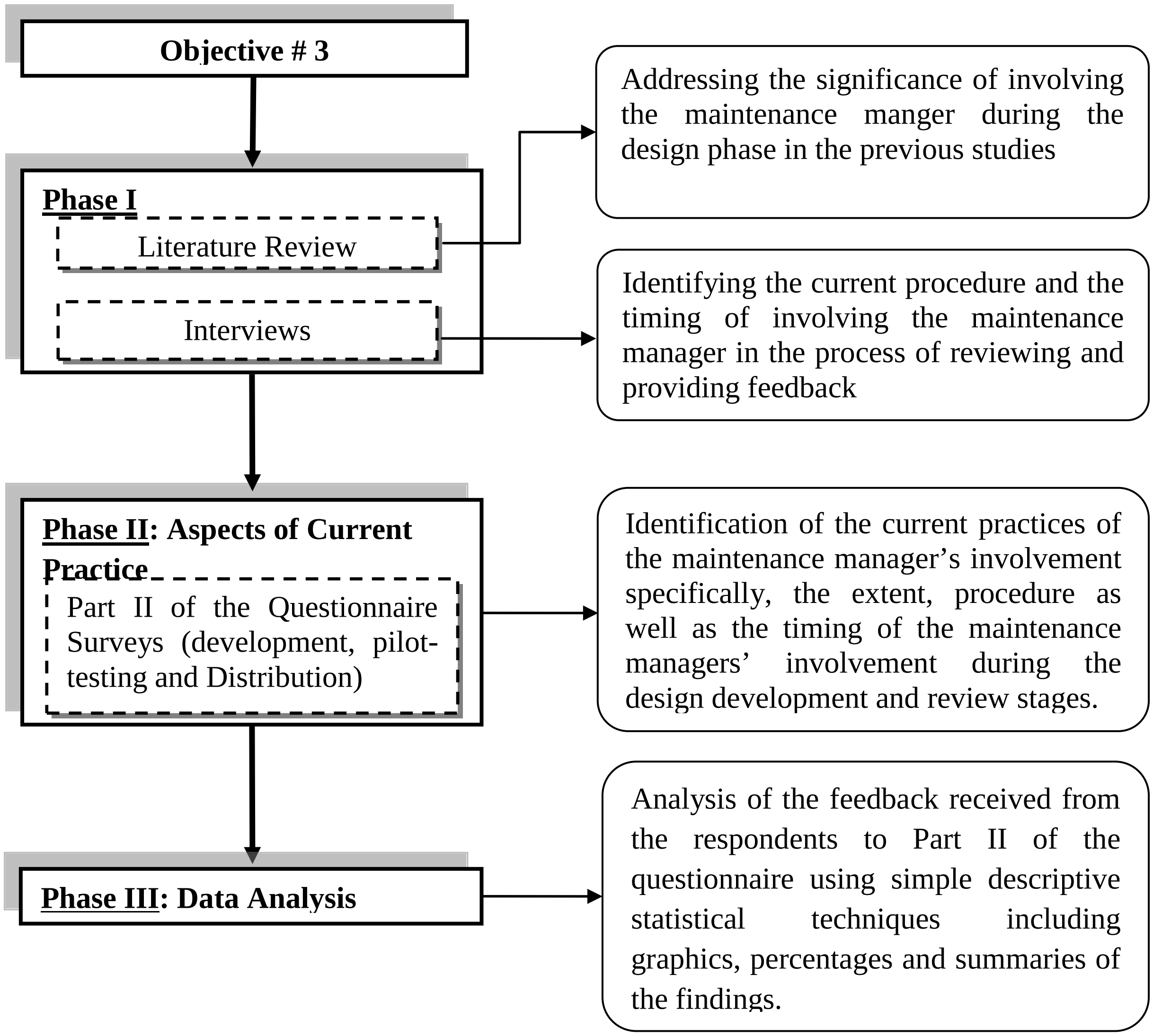

Figure 1.3: Research methodology for objective #2

1.6.4 The forth objective

The forth objective of this study is to develop a framework to prioritize the major concerns and /or details raised by the maintenance manager during the design development and review stages at the most significant project design stage. This objective will be achieved as follows:

<u>Phase-I: Criteria scoring matrix:</u> the research activities planned to achieve this phase include:

a) The pair-wise comparisons for the major concerns and/ or details (at the most significant project design phase) will be carried out in the criteria scoring matrix by three maintenance managers as subject matter experts. Selection of the experts will be based on their knowledge and experience in the field of building operation and maintenance, in addition to their frequent involvement during the design development and review stages.

b) The criteria scoring matrix for each expert will be evaluated to obtain the overall rank of each of the identified major concerns and/or details.

<u>Phase-II, Check consistency:</u> MATLAB program will be written to facilitate the analysis progress; since, it is not easy to determine the consistency manually. The concept of power method applied to the Eigen-value method use in this program was utilized.

<u>Phase-III, Correlation test:</u> a correlation check for the ranking of the set of concerns and/or details at the design development stage (60% of project design) will be performed. This check will be between the three experts ranking and the directors of maintenance department’s divisions (architectural, structural, electrical, mechanical, and HVAC) ranking. the research activities planned to achieve this phase include:

a) Calculating the rank correlation coefficient using spearman correlation since we have only two parties .The rank correlation coefficient (rho) will be calculated using the following formula (Al-Hammad et al., 1997):

The rank correlation coefficient (r) = $1-\frac{6\sum D^2}{N(N^2-1)}$

Where:

D= Difference between the ranks given by the two party for a particular concerns.

N = Number of concerns and/or details in this case.

b) Testing the correlation: In order to test the hypothesis that there is an agreement between the experts and the directors of maintenance mangers, ‘t’ test is used in this study. t-value is calculated using the following formula (Al-Hammad et al., 1997):

$$t = [(n – 2) * r^2 / (1 – r^2)^2]^{½}$$

Where:

r= the spearman correlation.

n = the number of observation (the number of concerns in this study).

Figure 1.4 illustrates the research methodology for the first objective # 4.

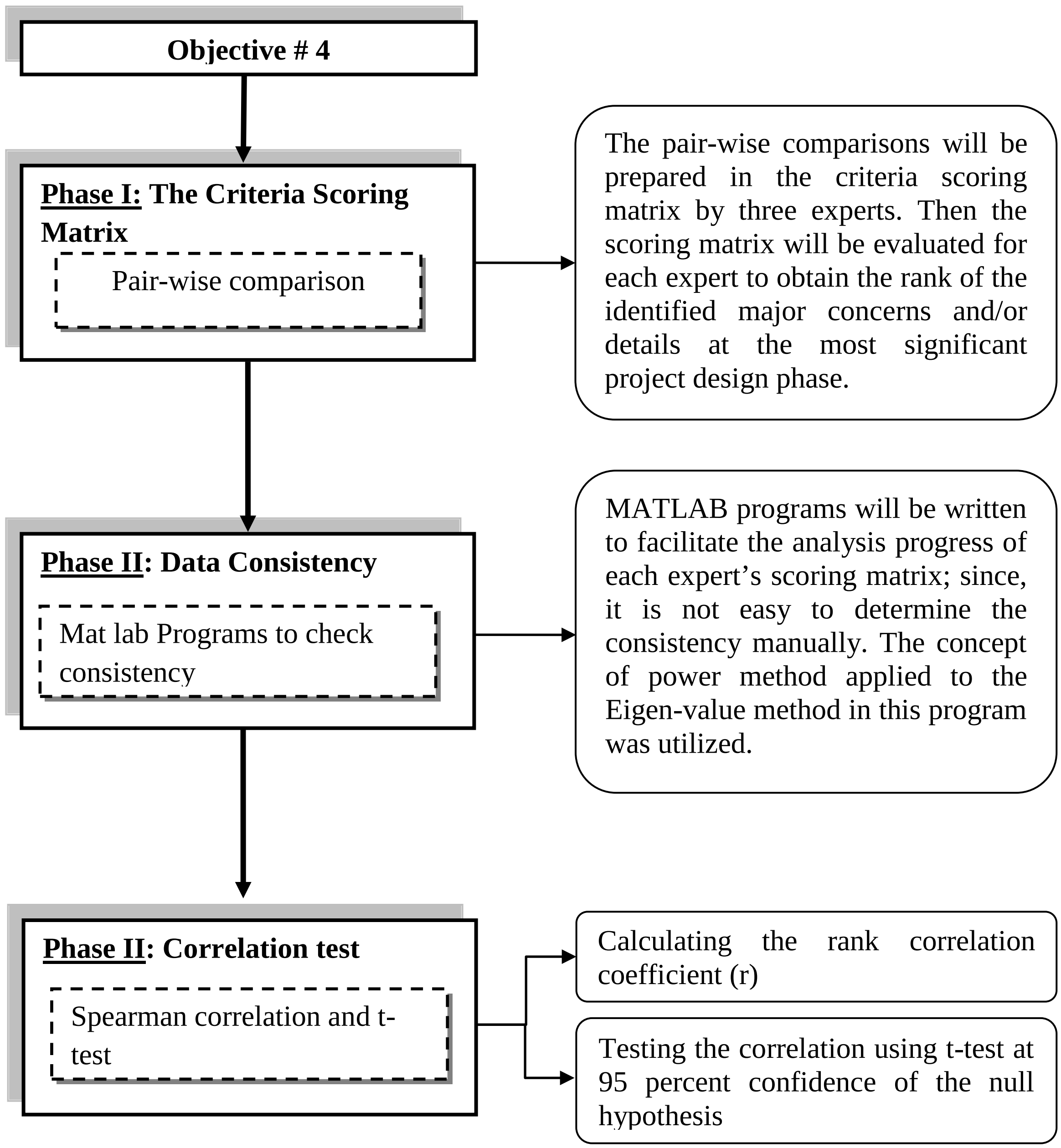

Figure 1.4: Research methodology for objective #4

1.7 THESIS ORGANIZATION

The thesis is divided into eight chapters to achieve the main objectives in accordance with the developed research methodology as follows:

Chapter One - Introduction

This chapter introduces the domain area of the research (facilities maintenance management). It includes a statement of the problem, the objectives of the study, its scope and limitations, significance of the study and research methodology.

Chapter Two - Literature Review

This chapter summarizes the literature related to traditional construction project process, design effects on facility operation and maintenance, design defects in buildings, definition of maintainability, why maintainability is important, how to improve the maintainability of the buildings and previous studies about the involvement of maintenance manager during design phase.

Chapter Three - Operation and Maintenance Problems

This chapter provides a thorough identification for the most significant operation and maintenance problems that commonly emerge as a consequence of the maintenance manager’s lack of involvement during the design development and review stages.

Chapter Four - Set of Concerns and/or Details

This chapter presents the identification for the major of concerns and/or details raised by the maintenance manager during the design development and review stages at different project design stages (i.e. 30%, 60% and 90%), which will have significant impacts on building maintainability in the future.

Chapter Five - Data Analysis and Results

This chapter presents the results of the assessment and data analysis of (1) The operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement and (2) The set of concerns and/or details raised by the maintenance manager during the design development and review stages.

Chapter Six - Investigation of the Current Practices of the Maintenance Manager's Involvement

This chapter presents the current practices of the maintenance manager's involvement specifically, the timing, procedure as well as the extent of the maintenance manager's involvement during the design development and review stages in Saudi Arabia.

Chapter Seven - Framework to Prioritize the Major Concerns and /or Details

This chapter presents the development of a framework to prioritize the major concerns and /or details raised by the maintenance manager during the design development and review stages at the most significant project design phase.

Chapter Eight - Conclusions and Recommendations

This chapter presents the conclusions and summary of the study. It also presents a number of recommendations, in addition to prospects for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 TRADITIONAL CONSTRUCTION PROJECT PROCESS

The traditional construction project process is a model which presents building delivery process in a linear or sequential manner. This linear model portrays the building process to start from the programming phase and end at operation and maintenance phase (Haviland, 1994; Erdener, 2003) as illustrated in Figure 2.1. A brief description of the traditional construction project process is as follows:

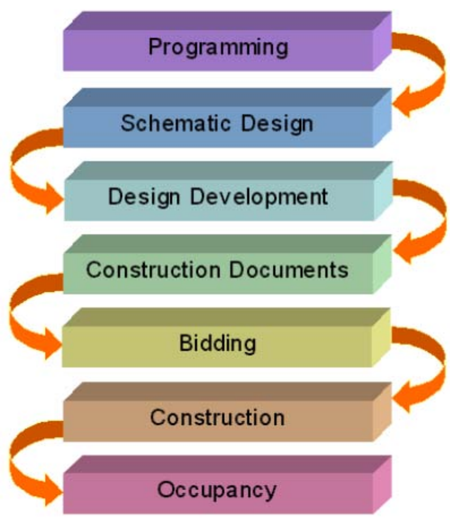

Figure 2.1: Traditional construction project process

2.1.1 Programming

Programming is defined by the American Institute of Architects (AIA) as "a problem-definition process that seeks and identifies issues and problems the design process is to address and solve"; it is a set of criteria on which the design is based on. Regardless of who is the programmer, he is responsible to get the approval, as well as understanding the client requirements (Erdener, 2003)

2.1.2 Design

Pati et al. (2002) defines facility design process as "a process of responding to a client's program that assesses alternative designs, systems, and subsystems within a first cost constraint". The purposes of the design process are to convert input to output as well as, focusing in all aspect related to space, time and finally how the integration of previous aspect generating the value for customers (Ballard and Koskela, 1998).

Ouzoonian (2005) describes the stages of the project design (drawing and specification) process as follows:

- **Concept Sketches**: this stage forms 10% of the project design. It reflects the areas required for the occupants, structural/ architectural columns layout, floors system, and façade materials. Sketches of this information are presented to the client.
- **Preliminary Design:** this stage forms 20% of the project design. All consultants contributing to the design, scheduling and construction is procured. An outline specification is developed depending on the preliminary project budget.
- **Design Development:** this stage forms 60% of the project design. At this stage, finishes materials are selected for façade and interior; the design of the structural system is finalized; the mechanical systems are defined; and the project cost estimate is prepared.

- **Construction Documents**: this stage forms 80%of the project design. At this stage, all members of the design team would be working to finalize and detail their works in order to prepare for the bidding phase. The technical specifications are prepared for each division of work.
- **Construction Administration Phase:** this stage forms 100% of the project design, either before or after signing the construction contract, a confirmed set of construction documents is produced.

Another study done by Structures NW LLC (structuresnw.com, 2011) indicates that the design process is divided into three stages as follows:

- **Schematic Design Development:** In this stage, all the important design areas will be reviewed with the client before the development of detailed drawings. In addition, the preliminary cost is provided to the owner in this stage. Activities carried out in this stage include:
    - Preparing preliminary building plans, elevations, and sections in order to determine space dimensions, volumes, circulation sketches, areas, space relationships.
    - Completing all room special furniture layouts, plumbing fixtures.
    - Preliminary selection of building materials.
    - Preliminary configuration of electrical, mechanical, and plumbing systems.
    - Responding to preliminary questions concerning the design of the structural system.

- Consideration of code requirements.
- Preparation of preliminary cost estimate (if required).
- Discussion of the design with the interested parties.

* **Design Development:** after the schematic design approval, all details are prepared, i.e. material selection and engineering systems. A more detailed specifications and cost estimate are provided at this phase. The package will be evaluated with the client before the next step of the design. Activities carried out in this stage include:
    - Completion of all the issues related to the design of the structural, cooling, heating, and lighting systems.
    - Coordination among all members of the design team.
    - Consideration of all construction methods and materials to construct the project.
    - Completion of all the requirements for the HVAC equipment, layout, and size.
    - Complete analysis of code issues.
    - Development of outline specifications, list all criteria for construction methods and materials.
    - Preparation of a detailed cost estimate, considering requirements of labor, materials and equipment.

- **Construction Documentation:** in this stage, the specifications as well as the construction drawings are packaged together; the contractor will use this package to build the project. Activities carried out in this stage include:
    - For bidding purposes, specific and detailed drawings should be prepared, also well written specifications of materials, construction methods, and contract requirements should be prepared as well.
    - In order to avoid any conflicts among various trades during construction, coordination sessions are held with consultants.
    - Resolution of any exceptional building or planning code issues.
    - Permits are obtained.

2.1.3 Bidding and Negotiation

In this phase the contract between owner and contractor will be drawn up. Activities included in this phase are (structuresnw.com, 2011):

- Preparation of documents for bidding purposes.
- Advisement to invite contractors to bid on the project.
- Supply bid documents to interested bidders.
- Check qualifications of bidders (references, insurance, experience, personnel).
- Preparation of addendas (if any).
- Held meetings with material suppliers and contractors.
- Receiving bids.
- Helping clients in the preparation of other essential documents and in the negotiation process.

2.1.4 Construction

In this phase, the project manager is coordinating the work, planning, scheduling, reviewing the total performance of the contractor and giving total feedback about the project to the designated building committee. The Construction phase is noticed to be an important phase, somehow like the design phase. Lê and Brønn (2007) claim that over many years no major improvement was carried out in the structural and construction phase. This will lead to future building difficulties.

2.1.5 Occupancy (Operation and Maintenance)

This phase is the most important phase among all. According to Lewis et al. (2010), the operation of any building will cost approximately 60 to 80 percent of the total life cycle cost of the facility, in comparison to the design and construction costs that consume approximately five to ten percent. The operational and maintenance phase of the facility is administered by the maintenance manager.

2.2 THE DESIGN PHASE

The design phase aims at translating the requirements of the clients into a design solution. This solution should be a facility that is economical and easily maintained.

2.2.1 Design Effects on Facility Operation and Maintenance

Faulty design represents 58% of all defects at the operation and maintenance phase (Seeley, 1987; Al-Hammad et al., 1997). The main causes for design-related maintenance problems are far and few communications between the building designers and maintenance managers. Al-Hammad et al. (1997) identify 35 design defects that affect the operation and maintenance of buildings. These defects are grouped under 6 categories as follows:

- Civil engineering faulty design.
- Architectural engineering faulty design.
- Maintenance faulty design.
- Consultant firm management faults.
- Specification faults.
- Building drawings faults.

Defects occurring at the design phase will reflect negatively on the operation and maintenance phase. Many studies show that the operation and maintenance phase is longer and costly than the design and construction phase. The operation of any facility will cost 50 to 80%, comparing with the design and construction that takes only 20-50% of total whole lifecycle costing of the facility (Giffin, 1993; Dunston and Williamson, 1999), as illustrated in Figure 2.2

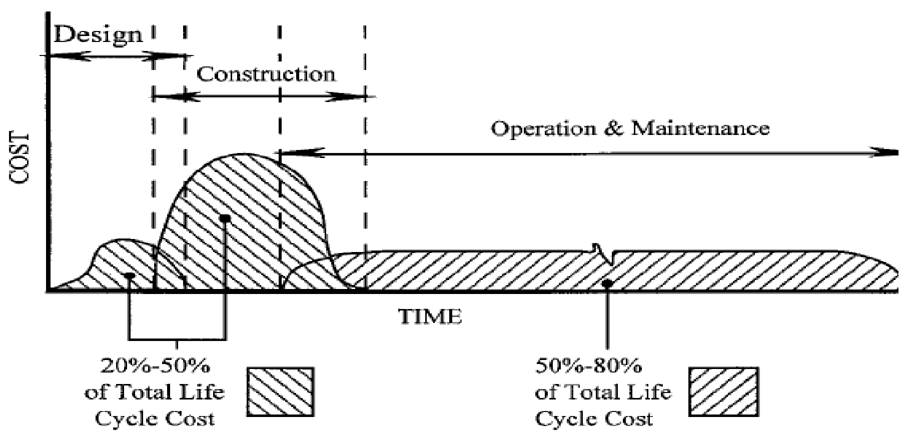

Figure 2.2: Life cycle costing (adapted from Giffin, 1993)

Assaf et al. (1996) stress that reducing maintenance work in the operation and maintenance phase is the result of reducing numbers of design defects.

Arditi and Nawakorawit, (1999a) indicates that faulty design leads to the occurrence of buildings defects which require costly maintenance. Designers should be keen to consider the effects of their decisions on the extent as well as the cost of maintenance during the life cycle of the building.

Chew et al. (2003) study 450 different types of building in Singapore and concluded that 68% of the defects are attributed to design, while 30% of these defects are attributed to poor construction. And only 2% of the defects are attributed to both, poor strategies and methods of maintenance.

Low and Chong (2004) study the most vital latent defect’s driver in the design. The study shows that at least 66% of the latent defects that appear during the operation and maintenance phase can be prevented at the design stage.

Ramly (2006) indicates that unplanned maintenance at the post occupancy stage can be reduced if the following design issues were considered seriously during the design phase:

- The building fabric, including walls, roofs, floors, windows and doors.
- Interior finishes, including wall, floors, and ceiling finishes.
- Special design features, including decorative components for the windows, glass and doors.

- Cleaning and housekeeping of all building components.

2.2.2 Design Defects in Buildings

Many researchers worldwide stress on the importance of the source of defects because of the escalating cost of maintenance (Assaf et al., 1996)

Ramly (2006) claims that the shape of the building and its element, construction technique to suit the design and choice of the material are major aspects that lead to design defects.

Also, inadequate information, wrong assumptions, unawareness, lack of knowledge and motivational factors are driving factors to design stages' defects (Andi and Minato, 2003).

Chong and Low (2006) indicate that there are three important causes for design-related defects. These causes are weather impacts with a total percentage of 52.76% of these defects, loads and moisture from wet area with a total percentage of 9.87%, and impact from occupants and loads with a total percentage of 24.33%. The remaining percentage of the defects is related to vandalism and accidents.

A study conducted by the UK Committee on building maintenance (ARIS, 2006) indicates that the design defects in buildings are caused by the following:

- Development of inadequate brief.
- Design inadequacies; nearly all design faults are attributed to faulty specifications, improper selection of materials, and lack insufficient provision of access to perform maintenance activities.
- Faulty construction and poor management.
- Defective materials and components.

2.2.3 How to Avoid Building Design Defects

Chong and Low (2006) propose five significant strategies for avoiding future design defect. These strategies are as follows:

- Testing material that will be exposed to adverse weather conditions. This strategy could result in preventing approximately 53% of design related defects.
- Accommodating the forces from resident and loads. This strategy could result in preventing approximately 14% of design related defects.
- Avoiding water leakage that causes other defects. This strategy could result in preventing approximately 11% of designs related defects.
- Improvement of specifications. This strategy could result in preventing approximately 8% of design related defects.
- Improvement of design clarity, design details, and layout. This strategy could result in preventing approximately 7% of design related defects.

2.3 MAINTAINABILITY

2.3.1 Introduction

Maintainability refers to ease of maintenance. This concept is far from being new; it was initiated by the United States military services in 1954 (De Silva et al., 2004). After a while, this concept becomes popular among many possessions like manufacturing of equipment and building construction. The concept of maintainability should be considered during the design and construction phase to reduce the cost and difficulty of maintenance works (Chew et al, 2008).

2.3.2 Definition of maintainability

Maintainability is defined as "a characteristic of equipment design and installation which is expressed in terms of ease and economy of maintenance, availability of the equipment, safety, and accuracy in the performance of maintenance actions" (Blanchard and Lowery, 1969; Wai-kin, 2008)

Building maintainability is defined as "the condition for an item or a surface that permits its repair, adjustment, or cleaning with reasonable effort and cost" (Fledman, 1975; Wai-kin, 2008).

Dunston et al. (1999) define maintainability as "the design characteristic which incorporate function, accessibility, reliability and ease of servicing and repair into all active and passive system components that maximizes costs, and maximizes benefits of the expected life cycle of a facility".

Chew (2010) defines maintainability as “the ability to achieve the optimum performance throughout the lifespan of a facility within the minimum life cycle cost (LCC)”. Figure 2.3 illustrate maintainability definition.

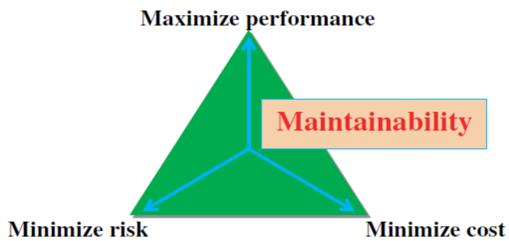

Figure 2.3: Maintainability definition (Chew, 2010)

For ease of maintenance concept, all the new buildings should have maintenance manual. Development of the maintenance manual requires the collaboration of design firms, maintenance firms and the customer (ARIS, 2006).

2.3.3 Statistics for Maintainability Factor at the Design, Construction and Operation and Maintenance Phase

The numbers of maintainability factors (like accessibility) in the design phase is greater that other phases. As illustrated in Table 2-1, there are four types of building system, namely architectural construction, mechanical and electrical. These systems also include subsystems. The total numbers of maintainability factors in entire building are 731 factors (100%). Between these factors, 382 factors are in the design phase (i.e. 52.5%) while the construction phase have 179 factors (i.e. 24.5%), and 169 factors are in operation and maintenance phase (i.e. 23%). From these numbers and percentage, it is obvious that the design phase is the most critical phase to take into consideration these maintainability factor (Chew, 2010).

Table 2-1: No. of maintainability factors availability (Chew, 2010)

System	Subsystem	Total	Design No.	Design %	Construction No.	Construction %	Maintenance No.	Maintenance %
C&A	Basement	63	30	47.62	24	38.10	9	14.29
	Façade	79	42	53.16	26	32.91	11	13.92
	Wet area	59	32	54.24	18	30.51	9	15.25
	Roof	64	35	54.69	21	32.81	8	12.50
	Avg.	66.25	34.75	52.43	22.25	33.58	9.25	13.99
M&E	San-plumb.	93	49	52.69	25	26.88	19	20.43
	HVAC	92	54	58.70	12	13.04	26	28.26
	Elevator	84	44	52.38	10	11.90	30	35.71
	Electrical	107	57	53.27	23	21.50	27	25.23
	Fire prot.	90	39	43.33	20	22.22	30	33.33
	Avg.	93.20	48.60	52.07	18.00	19.11	26.40	28.59
Entire bldg.		731	382	52.26	179	24.49	169	23.12

2.3.4 Why Maintainability is Important

As modern facilities are designed to meet higher standards, the effect of the decisions made during the planning and design stage would have a far reaching effect and significant impact on the future maintainability of a facility. Decisions made during the planning and design stages will be reflected either positively or negatively on the maintainability of the facility. As illustrated in Figure 2.4 , the expectation of the facility users and owners for maintenance approach before 1980 was corrective approach. Between the years 1980 and 2000, the facility users' expectation shifted from focusing on corrective maintenance to preventive maintenance. In the years 2000 and above, the expectation shifted towards predictive maintenance (Chew, 2010).

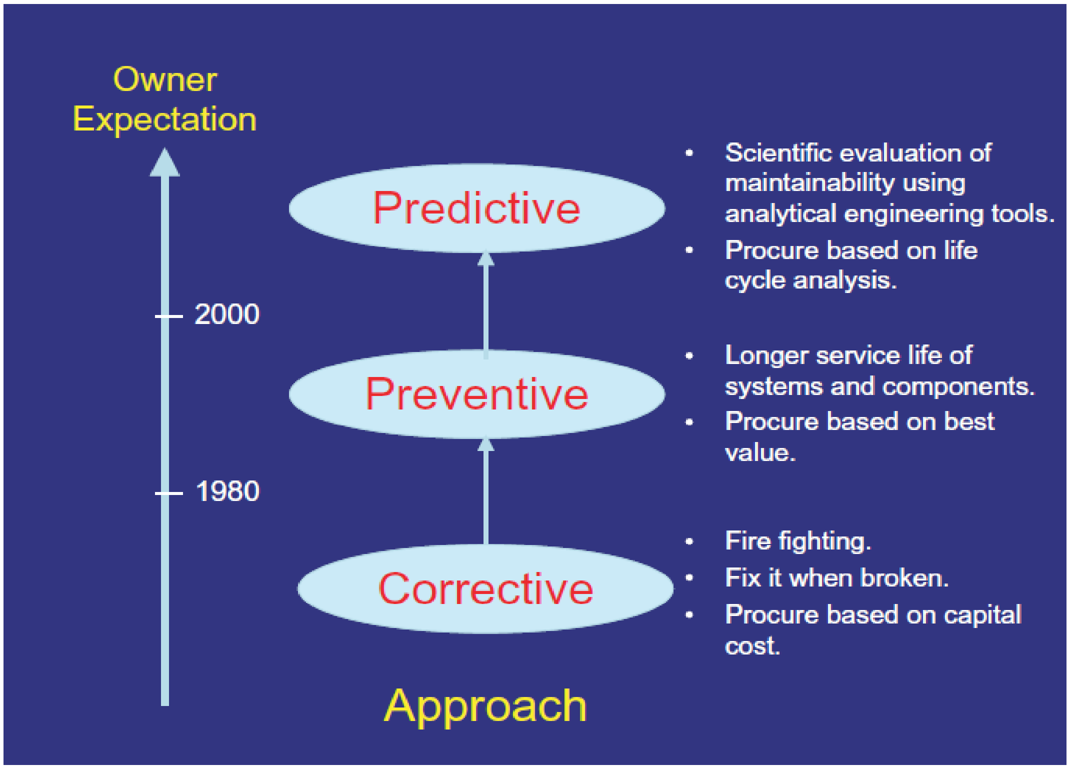

Figure 2.4 User Expectation for maintenance (Chew, 2010)

2.3.5 How to Improve the Maintainability of the Buildings

According to Chong and Low (2006), the maintenance manager has less control on minimizing maintainability defects (i.e. about 4%) during the occupancy, while the maintenance manger with the designer support could overpass almost all these defects (i.e. about 84%).

De silva (2011) indicates that there are fifteen common maintainability defects. A twenty six important factors related to design phase were developed by building maintenance manager, facility manager and building manager, and debated under six groups as follows:

- Consideration of future maintenance requirements.
- Involvement of facilities management personnel in the design phase.
- Accessibility of future maintenance.
- Considerations of climatic conditions.
- Consideration of future maintenance budget.
- Sufficient detailing.

De Silva et al. (2004) perform a study about improving maintainability of buildings. This study identifies the leading eight measures for improving and enhancing maintainability. These measures are:

1. Providing programs in development and training on maintainability.
2. Providing guidelines that help in achieving high maintainability though construction industry.
3. Providing sufficient data on cost and performance to achieve client requirements during the life cycle of the structure/building.
4. In order to assist decision making, information on maintainability of the structure component and materials should be provided by designer and supplier.
5. A new maintainability score like that measuring build ability should be established.
6. The selection of successful tender by client is specifically depends on total life cycle cost instead of initial cost only.

7. The liability period of defects for any structure / building should be extended more than 1 year.
8. Enlarge using of design-build procurement system.

2.4 PREVIOUS STUDIES

Many studies on the literature have the awareness about (1) the importance of the maintenance manager's feedback to the integrated design team, and (2) and how such feedback from operation and maintenance phase could be occurred.

(Arditi and Nawakorawit, 1999 a,b) conduct a survey in the United States, asking the largest 211 building design firms about communication with the maintenance manager. The findings confirmed the importance of communication between the maintenance manger and the designer through the design phase. One question in the survey asks if the communication between maintenance manager and the design firm take place. As illustrated in Figure 2.5, about 85% of the designers make communication at this phase in one way or another. The reason is that designers have no experience in maintenance and rarely assesses the performance of the building according to it.

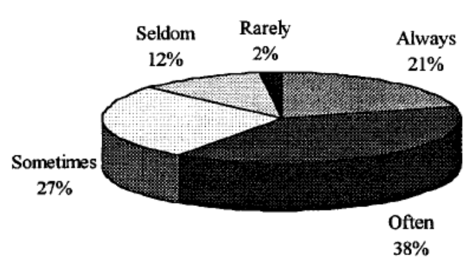

Figure 2.5: Frequency of Communication between Designers and maintenance manager (Arditi & Nawakorawit, 1999)

Dunston and Williamson (1999) develop a model for best practices that takes lessons learned from the design, construction and operation and maintenance phase. The model consists of a plan for improving the assessment of future facilities' needs and improving design standards by avoiding the same mistake, as illustrated in Figure 2.6

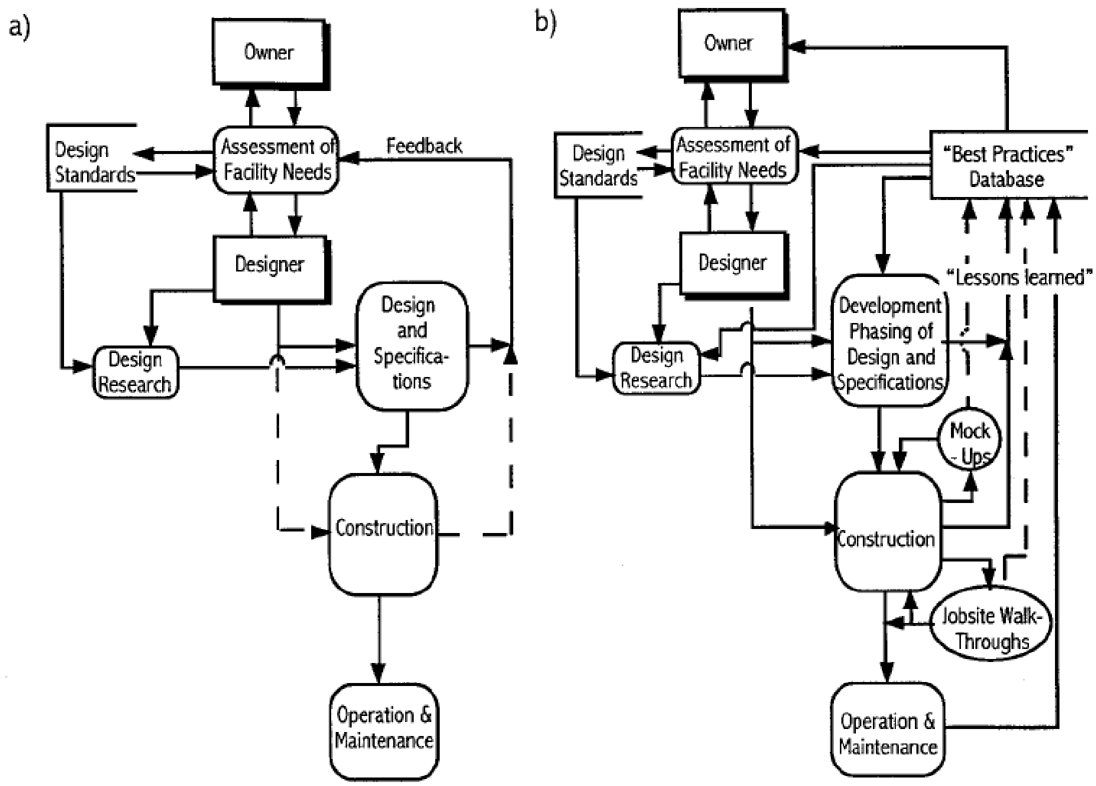

Figure 2.6 Design Information Diagram: (a) conventional Design and Construction Feedback; (b) future Design and Construction (Dunston and Williamson 1999)

Building Research Establishment (BRE) carries out a research on bringing facility expert to the design process, the report concludes that involving facilities manager should result in buildings that are (Jaunzens et al, 2001).:

- Meeting business requirements.
- Attractive to owners.

- Easy to maintain and commission.
- Easy to manage and control.
- Cost effectiveness for operation.
- Capable of responding to requirements of the occupants.

Proposing to modify the traditional construction project process, Erdener (2003) claims that there is a missing communication gap in addition to lack of proper information among all parties of this process starting from the fund until managing facility resources. The modified process takes into account the facility manager's voice that can add realistic user requirement. The modified process is illustrated in Figure 2.7

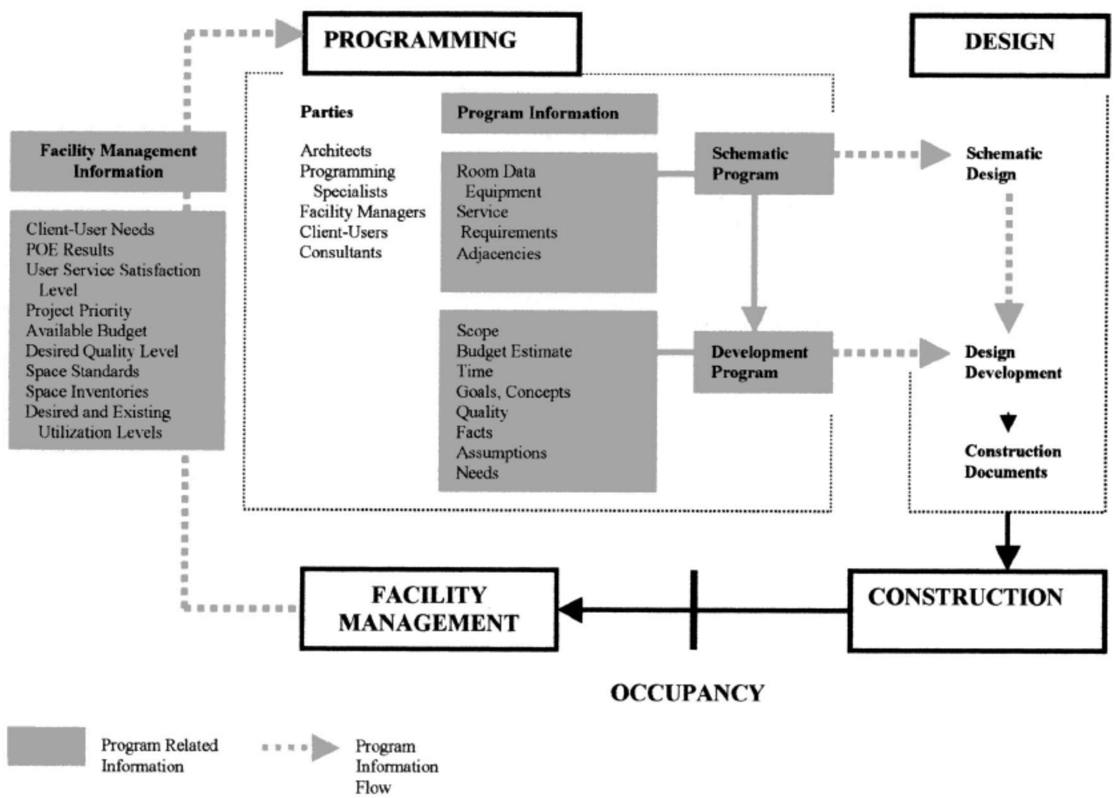

Figure 2.7: Modified traditional construction project process (Erdener, 2003)

Aris (2006) stresses that the maintenance manager should be consulted at the design development and review stages. Such consultation provides for identifying the maintenance problems to the design firm, the strength and weakness of these problems, and their maintenance method. Also the maintenance manager would be gaining familiarity with the effects of made changes. These will lead to minimize the maintenance expenditure and preserve the asset

SOMOROVÁ (2007) assumes that there are three main partners who have an important task in the design stage. These partners include the developer who has dozen of ideas, the architect who draws the ideas of the developer and increases the functional efficiency of a building's design, and the facility manager who has sufficient practice and has a wide knowledge in many areas. The tasks of the facility manger during the design development and review stages are "keep the space competitive in an evolving market; minimize operating costs, maintenance costs, costs for repair or innovation and energy costs". According to these experiences, the facility manager's involvement during the design development and review stages is very significant.

Lê and Brønn (2007) propose linking experience and learning. They suggest a model for principal feedback processes as illustrated in Figure 2.8. This model depicts how the feedback occurs between the operation and maintenance phase of one completed project and the design and construction phase.

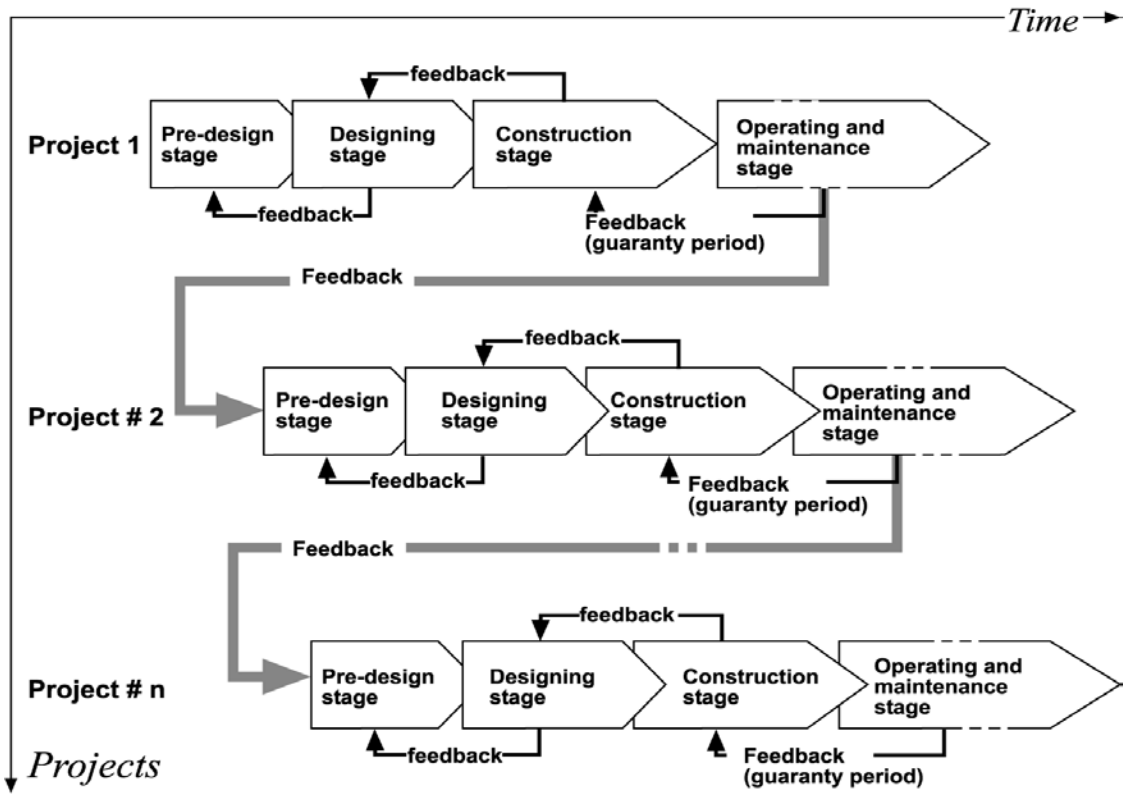

Figure 2.8: Principal Feedback Processes (Lê & Brønn, 2007)

According to literature and case studies from the Nordic countries in Europe, Jensen (2009) supports the fact that "a typology of knowledge transfer from building operation to building design is presented based on a combination of knowledge push from building operation and knowledge pull from building design". This topology results in the following four mechanisms:

1- Codification of knowledge from building operation, which can increase the awareness among the designers.

2- Competences among the maintenance managers, which can increase the awareness among the designers.

3- Power to ensure that the designers take building operation considerations seriously by using the competences of the maintenance managers.

4- Power to ensure that codified knowledge from building operation is used by the design team (Jensen, 2009).

Mohammed and Hassanain (2010) explore the involvement of maintenance manger in the design stage, and how this step reduces maintainability defects occurrence in the operation and maintenance phase of the facilities. The study has combined the job of the maintenance managers during the architectural design phase in order to provide for both ease of maintenance and quality improvement of the construction. The study concludes that the maintenance manger should be involved on the design phase, and have an active participation with the integrated design teams. Figure 2.9 illustrate their proposed model for the involvement.

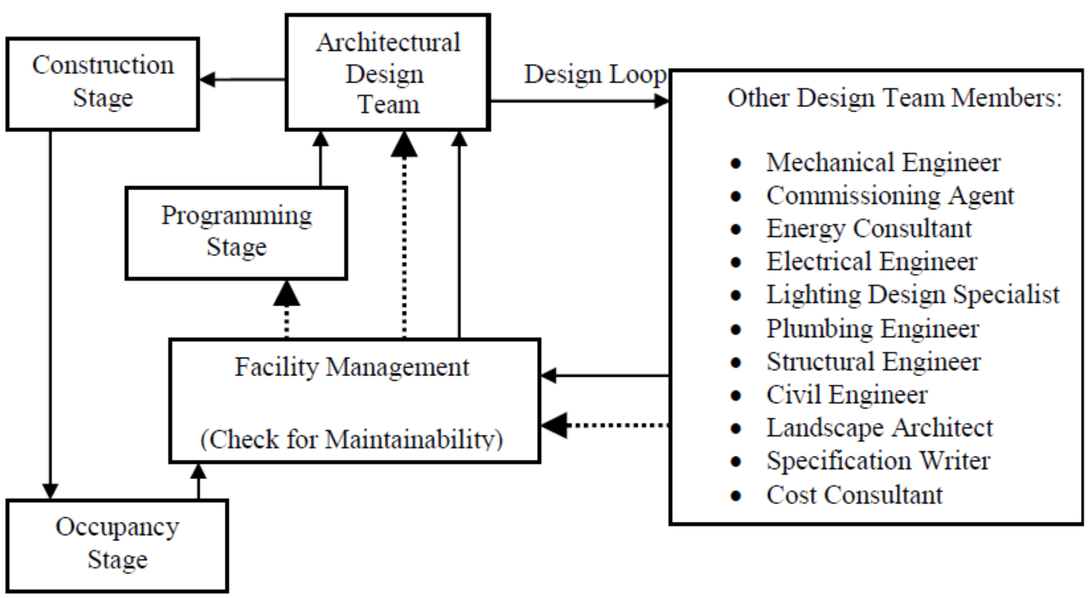

Figure 2.9: involving the maintenance manager with design team (Mohammed & Hassanain, 2010)

2.5 THE RESPONSIBILITIES OF THE MAINTENANCE MANGER DURING THE DESIGN PROCESS

El-Haram and Agabiou (2002) identify the responsibilities of the maintenance manager during the bid development and design processes. These responsibilities include:

- Developing facilities management cost break down structure that include operation and maintenance occupancy and replacement.
- Facilities management costs estimation.
- Evaluating and reviewing the design from different points view such as operability, maintainability, serviceability, and maintenance.
- Determination and choosing the facility optimum replacement strategies and maintenance.
- Determination and choosing the optimum scenario for operation.
- Coordination between design and construction team to choose most appropriate cost–effective design option that will enhance whole life cycle of the facility.

2.6 DISCUSSION

This chapter summarizes the literature related to traditional construction project process, design effects on facility operation and maintenance, design defects in buildings, definition of maintainability, why maintainability is important, how to improve the maintainability of the buildings and previous studies about the importance of the maintenance manager's feedback to the integrated design team, and how such feedback from operation and maintenance phase could be occurred. The purpose of this literature was (1) to identify the common operation and maintenance problems that are attributed to the lack of the maintenance manager’s involvement during the design development and review stages (2) understanding the working mechanisms of technical building systems in order to list a set of concerns and or details raised by the maintenance manager during the design development and review stages which will have significant impacts on building maintainability in the future and (3) Addressing the significance of involving the maintenance manger during the design phase in the previous studies. The literature revealed the importance of maintenance manager’s involvement during design development and review stages. As such involvement will reduce the operation and maintenance problems.

CHAPTER 3

OPERATION AND MAINTENANCE PROBLEMS

3.1 BACKGROUND

This chapter provides a thorough identification for the most significant operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during the design development and review stages. A series of sixty six operation and maintenance problems were identified and described. Identification of these factors was carried out based on review of the published literature and interviews with the maintenance department's engineers of two universities, namely King Fahd University of Petroleum and Minerals and Dammam University.

3.2 OPERATION AND MAINTENANCE PROBLEMS

The operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during design development and review stages were classified under five groups, namely architectural design problems, structural design problems, electrical design problems, mechanical design problems, and HVAC design problems. The following sub-sections present a description of these various types operation and maintenance problems.

3.2.1 Architectural Design Problems

This category includes sixteen architectural design problems. They are referred to as (ADP 1 to ADP 16).

ADP 1. Inability to entirely reach and maintain the fenestration due to the architectural form of the building

Architects should aim to minimize irregular architectural forms in the design of building fenestrations. These irregularities provide for difficulty in reaching and maintaining the fenestrations where collections of moisture, dust or water take place (Al-Hammad et al.1997). Ramly (2006) and Chew (2010) confirms that although irregular building fenestrations provides for attractive forms, maintenance of such forms could be problematic. This could be resolved by the installation of special equipments that are fixed permanently to the structure of the building to provide a platform to carry out the required maintenance. Chew (2010) describes seven types of building forms that directly impact on the provision of access system to carry out the required maintenance in a building. These forms are as follows: (1) the regular and plain form which allows for easy provision of access system; (2) the plain circular form which allows for easy provision of access system where no corners are present, (3) sloping face which has small roof space due to building form; (4) stepped roof which has reduced roof space and different access systems which may need to be provided in each roof; (5) staggered face which has numerous corners that require the access system to change over at each turn of corner; (6) sloping roof which has minimal roof area for storage and operation of access system; and

(7) pointed roof which also has minimal roof area for storage and operation of access system.

ADP 2. Insufficient availability of specific building materials in the market when replacement of the same is required

Architects should specify building materials that are commonly available and used in the project's location. These materials should require less maintenance during life cycle (Al-Hammad et al, 1997; Hassanain and Harkness, 1998; De Silva et al, 2004; Chew, 2010). Architects are in need for updated building materials database that support design inputs pertaining to the selection of materials in the vicinity where they project is located. Absence of such databases may result in using materials that are difficult to substitute when the original ones need to be replaced (Ramly, 2006).

ADP 3. Inappropriate selection and specification of specific building material for incorporation in the project

Architects need to be aware of the performance and the installation requirements of the specified material that will be incorporated in the project (De Silva et al, 2004; Aris, 2006; Chew, 2010). Resistance to cracking, dampness, chipping, staining such as biological growth, and chemical attack are among the significant performance requirements that architects need to be aware of (De Silva and Ranasinghe, 2010). Chong and Low (2006) indicate that the use of appropriate building materials will result in preventing more that 53.08% of the design latent defects that may be found in interior wall, exterior walls, ceiling, door and windows.

ADP 4. Propagation of foul odor due the placement of kitchens and toilets in the direction of the prevailing wind

Propagation of foul odors is one of the problems the architects are unaware about when specifying window locations. This problem occurs due to the installation of internal divisions without taking into consideration the direction of the prevailing wind (Chew, 2010). According to maintenance department at KFUPM, this problem is frequently occurring at Al-Ferdous Neighborhood. The foul smell starts propagating during the period of the year where the outside temperature is less that the average one (Al-Kafrawi, 2011).

ADP 5. Design and placement of large windows in building elevations facing the solar path and wind direction

Nowadays, buildings are not in need for large windows or more air ventilation as before because natural resources such as wind and sunlight can always be substituted with air-conditioning and electrical lighting (Aris, 2006). Large windows that are facing the solar path should be reoriented in order to avoid direct exposure to the heat especially in hot, arid climates (Chong and Low, 2006). Additionally, large window facing the direction of the wind will be subjected to water seepage due to rainfall (Chew, 2010).

ADP 6. Difficulty in moving the furniture and equipment within interior spaces due to the limited width and height of doors

Difficulty in moving the furniture and equipment within interior space is a common problem that face the operation and maintenance team due to in appropriate design and non-compliance with architectural standards (Ramsey and Sleeper, 2008). In addition, this common concern occurs as result of lack of consultation between architects and interior designers during the programming stage to document the needs of the client for interior spaces and their functions (Mazarella et al, 2011). Al- Kafrawi (2011) indicates that the solution to this problem involves installing another door or increasing the dimensions of the existing one. This will result in additional unanticipated maintenance cost during the operation and maintenance stage.

ADP 7. Wall edges that could chip due to impacts of loads and occupants

Sharp wall edges are subjected to frequent damages due to loads and occupant circulation. Although installed protection made out of rubber or metal to sharp wall edges might be costly, these protective material will prevents damages to sharp wall edges and avoids future costly repairs (Chong and Low, 2006). De Silva and Ranasinghe (2010) indicate that architects should be aware of the various properties of materials, especially resistance to chipping, before they are being specified.

ADP 8. Specification of low quality tiles that could be heavily stained or degraded due to heavy human traffic and weather condition

Tiles could be stained or subjected to degradation due to heavy human traffic and dampness conditions (Chew et al, 2004; Chong and Low, 2006). Architects need to be aware of two significant factors that can impact on the quality of tiles. These factors are the climatic conditions where projects are located in and occupant loads. Therefore, architects need to be aware of the abrasion resistance of any specified materials. Chew and ping (2003) indicate that to offset satins on external wall tiles that would usually be concentrated at the mortar joints due to its porosity and absorption, these external wall tiles should be glazed to mask unwarranted dirt stains.

ADP 9. Signs of stains and seepage due to improper rainwater drainage around windows

Rainwater is known to be a major cause for stains on façades and water seepage to the inside of the building (Chew and Ping, 2003; Chew, 2010). Stains and water seepage are two major defects which cannot be prevented in cases of wind driven rain (Chew, 2010). Flores-Colen et al (2008) confirms that stains on façade around windows are attributed to deficient detailing such as lack of provision of dripping-pan and stooling, as illustrated in Figure 3.1.

Figure 3.1: Staining problem in windows-sills (left), introduction of stooling and dripping-pans (right). (Flores-Colen et al, 2008)

ADP 10. Visibility of signs of stains and development of moulds due to inadequate means of ventilation (natural or mechanical or a combination of both)

Ventilation could be provided by mechanical or natural means, or combination of both. Ventilation enhances dryness of wet areas; thus prevents the development of moulds, fungi and biological staining, as illustrated in Figure 3.2 (Chew et al, 2004; Sobotka and Thriene, 1996; Ishak et al. 2007; Chew, 2010). Ishak et al. (2007) indicates that lack of provision of windows in kitchens and bathrooms is a live example.

Figure 3.2: Fungi and biological staining (Chew, 2010)

ADP 11. Signs of stains on the building façade due to the different levels of moisture absorption of building materials

Porosity and roughness of the building materials used in the development of façades are possible causes for façades staining due to their exposure to rainwater (Flores-Colen et al, 2008; Chew, 2010). Moreover, different composite building materials have different absorption levels. This will cause staining of the façades (Cook and Hinks, 1992; Ishak et al, 2007).

ADP 12. Moisture and vapor traveling from wet to dry faces

Moisture and vapor penetrating from the external face to the internal face of the walls will degrade the internal finishes, as illustrated in Figure 3.3, due to lack of air/vapor barrier provision (Hassanain and Harkness, 1998). This design defect in buildings is attributed to poor detailing of the insulation and the use of inappropriate sealant. These cause moisture and water penetration through the wall (Ghassan, 2003; Ishak et al., 2007). Architects should take into account the effects of wind on moisture migration, and improve specifications and materials quality (Chong and Low, 2006; Chew et al., 2003).

Figure 3.3:Leakage through porous concrete (Chew, 2010)

ADP 13. Plaster decay on external wall surface due to dampness

Rising dampness will affect both internal and external faces of walls. In external wall surfaces, the dampness from rain will cause the plaster to decay, which may impair the paint on the internal side of the wall in addition to the encouraging the growth of moulds (Ishak et al., 2007; De Silva, 2011). Another factor that increases façades dampness is the connection points with the soil. In this case, the dampness will be withdrawn from the soil at the connection points causing the plaster to crack (Chew, 2010) as illustrated in Figure 3.4

Figure 3.4:Plaster decay on external surface due to dampness (The Author, 2012)

ADP 14. Specification of dark color paint as an exterior finish in hot, arid and dusty regions

Specification of dark color paint as an exterior finish in hot, arid and dusty regions is a design defect (Al-hammad et al., 1997; Ishak et al., 2007) that would require extensive cleaning and maintenance efforts. This defect occurs as a result of lack of communication between the maintenance manager and architects when specifying exterior finish materials (Al- Kafrawi, 2011).

ADP 15. Paint peeling, flaking, blistering, biological attack and efflorescence

Paint defects are frequent, costly maintenance problems in many projects (De Silva, 2011). There are many paints defects that occur as a result of faulty design. These defects include (1) use of paints that are not reliable with poor adhesion qualities. Such qualities will affect the useful life of that paints. (2) Paint peeling, flaking as a result of moisture migration through walls during high level of humidity in the indoors, especially in kitchens and bathrooms where vapor barrier is not provided, as illustrated in Figure 3.5. (3) Biological attack and dirt stain due to not using anti-fungal paint when wall design features allow for collection of rain at some areas. This results in an increase in dampness (Chew and Ping, 2003; Chew, 2010). According to Chong and Low (2006) there are more than 240 major internal wall defects that cause paint flaking and peeling. 138 of these defects are attributed to poor design. The main causes of these defects are moisture from wet areas, weather, and activities of occupant. These design defects can be prevented by improving specification, preventing causes of leakages and improving design details.

Figure 3.5: Paint peeling and flaking (left), paint blistering (right) (Chew, 2010)

ADP 16. Inability to maintain vertical risers due to the limited areas of the service shafts

One design related fault that is attributed to the communication gap between design teams and maintenance engineers is the lack of available space in the service shafts (De Silva, 2011). Providing an adequate space in the service shaft for containing all ducts and pipelines would facilitate for easy access to maintain these mechanical systems. Also maintenance can be carried out without the need to enter to the toilet areas and disturb the tenants (Hassanain, 2005; Chew, 2010).

3.2.2 Structural Design Problems

This category includes eight structural design problems. They are referred to as (SDP 1 to SDP 8).

SDP 1. Signs of cracks around columns and beams due to inadequate structural design

Cracks appear in columns and beams after a period time once the building undergoes operation. These cracks occur due to inappropriate structural design of these elements (Al-hammad et al., 1997; Chew, 2003). Proper specifications of concrete mix and adequate detailing for the structural design have the potential to minimize the occurrence of cracks (De Silva and Ranasinghe, 2010). Chew (2010) believes that all these cracks appear due to thermal movement between steel and concrete, and inadequate design for deflection occurrence.

SDP 2. Cracks in floor slabs, walls, and tiles due to differential settlement

Differential settlement of structures most likely occurs due to expansive clay. This will result in the development of significant structural cracks in walls and floors. The occurrence of these cracks could be alleviated by conducting more soil tests (Chong and Low, 2006). (Chew, 2010) indicates that cracks caused by differential settlement occur in virtually all types of façade including: masonry walls, pre-cast concrete cladding, plastered walls, tile cladding, and natural stone cladding, as illustrated in Figure 3.6. The scale and severity of the cracks are affected by the exposure to the climatic conditions where the building is located (Silva, 2011).

Figure 3.6: Exterior cracks (Chew, 2010)

SDP 3. Corrosion of steel reinforcement bars due to insufficient concrete cover

Insufficient concrete cover may allow the corrosion of the steel reinforcement that leads to concrete cracking and spalling, as illustrated in Figure 3.7 (Al-Hammad, 1997; Chew et al. 2004). De Silva and Ranasinghe (2010) indicate that proper concrete cover, detailing of joints and concrete mix contribute effectively towards the development of high performance slabs with less frequent maintenance problems. Other factors that contribute to the corrosion of steel reinforcement include high permeability of concrete due to low water cement ratio, specification of reinforcement bar that could easily corrode in hot humid climates and seepage of water from floor drainage in concrete slabs (Chew, 2010).

Figure 3.7: Corrosion of steel and spalling of concrete (The Author, 2012)

SDP 4. Tile deponding, adhesive failure, cracks and fraction at weak points due to expansion and contraction stresses

Thermal movement can cause many defects such as fraction at weak points, cracks in plaster, and adhesive failure and tile deponding, as illustrated in Figure 3.8. These defects lead to water penetration in walls and roofs (Ishak et al., 2007). This problem occurs due to inappropriate design of expansion joints in addition to the regular expansion and contraction (Chong and Low, 2006; Chew, 2010).

Figure 3.8: Tile cracks and deponding (Chew, 2010)

SDP 5. Moisture and dirt infiltration through expansion joints due to inefficient filling materials and sealant

Expansion joints should be filled with insulating materials, then waterproofing at floor level should be added. Finally sealant would be installed to seal any moisture infiltration. This will eliminate the development of stains and cracks (Al-Kafrawi, 2011; Chong and Low, 2006). Figure 3.9 illustrates the inefficiency of the sealant type.

Figure 3.9: inefficiency of sealant type

SDP 6. Sign of moisture penetration in the basement at beam-wall joints, walls, and ceiling-wall joints due to insufficient waterproofing and insulation

Cracks in basements are usually noted at the construction joints between beams and walls as well as on the joints of ceilings and walls, as illustrated in Figure 3.10. These cracks result from failing to accommodate the settlement of soil (Al-Kafrawi, 2011). With the lack of provision of a waterproofing membrane, these cracks may provide a channel for water seepage (Chew, 2010).

Figure 3.10: Beam-wall joints' moisture penetration (Chew, 2010)

SDP 7. Damage to underground pipelines due to the settlement of soil and foundations

Underground pipelines are used for water distribution or plumbing systems may get damaged due to soil or foundation settlement (Chew et al. 2008). The specifications should include clear clauses about compaction of soils in addition to provisions for conducting more soil tests before the design of foundations (Al- Kafrawi, 2011).

SDP 8. Plaster crack between concrete brick joints and wall-floor joints

Plaster cracks in interior walls is a problem that is usually found between concrete brick joints and wall-floor joint. These cracks are believed to be a settlement cracks that occur due to lack of specification of mesh between joint (Al-Kafrawi, 2011). There is a need to accommodate the movement between two different elements (Chong and Low, 2006).

3.2.3 Electrical Design Problems

This category includes thirteen electrical design problems. They are referred to as (EDP 1 to EDP 13).

EDP 1. Short circuits due to overload occurrence in plug points

Short circuits occur due to improper size, center line spacing and low resistance cabling which are provided in the circuits that have high electrical loads. Frequent short circuits result in damaging the insulation which would require replacing the cables. Current overloads occur in plug points due to the use of extension cords with multi plug points, where non-fused circuit breakers are provided, as illustrated in Figure 3.11 (Chew, 2010; Alam, 2011).

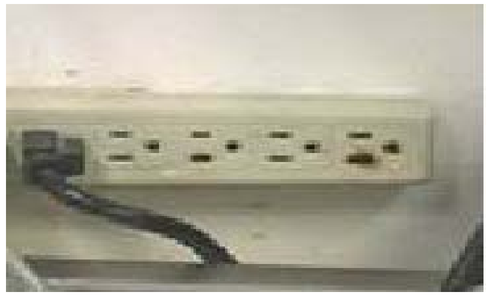

Figure 3.11: Multi- plug points at one plug (Chew, 2010)

EDP 2. Insufficient number and distribution of plugs points

Both insufficient number and inappropriate distribution of plug points are two design defects that lead to operation and maintenance problems. These problems are frequent in kitchens where many electrical appliances are used such as refrigerators, microwaves, and mixers (Alam, 2011). Inappropriate distribution will lead to the use of adapters and extension cords that cater for too many devices, as illustrated in Figure 3.12 . Such conditions result in the development of short circuits and overheated cables. Inappropriate distribution of plug points is attributed to poor planning for future extension as well as accommodation for furniture layout (Chew, 2010).

Figure 3.12: Extension cords that cater for too many devices (The Author, 2012)

EDP 3. Total power cut from one fault

It is recommended that each plug point has its own circuit breakers, especially where high electrical loads are located. This will ensure that power cut offs at these points are limited to their locations (Alam, 2011). The lack of a circuit breaker at every portion of the space will lead to a total black out in all the areas (Chew, 2010).

EDP 4. Exposed cabling and loose connections

Lack of plug points necessitate the use of exposed extension cords. Further, provision of electrical current to power additional luminaries requires the use of external cables that pass through plastic tranches (Alam, 2011). Loose or inefficient connections between these external cabling will result in the development sparks or electrical arc, overheating and eventually burning the cables (Chew, 2010).

EDP 5. Exposed Plugs at open and wet areas

It is recommended to use rain type plugs at open areas such as gardens, non-covered terraces, or at wet areas such as bathrooms and closets where condensation occurs. Failing to add this rain type plugs at these locations will lead to continuous occurrence of short circuits (Alam, 2011).

EDP 6. Flickering and blinking of fluorescent lamps

Flickering and blinking of fluorescent lamps is caused by voltage dip. Voltage dip occurs where the length of the cables between the fused splitter and the lamp is too long, and where there is a lack of provision of fuse or circuit breaker (Chew, 2010). Flickering fluorescent tubes indicate the occurrence of a fault in the fitting that may give rise to intense localized heating, which is sufficient to cause a fire, as illustrated in Figure 3.13 (Alam, 2011).

Figure 3.13: Fluorescent lamp defects due to flickering (Chew, 2010)

EDP 7. Placement of light switches far away from access points

Light switches should be placed near access points. Sometimes, the electrical designer overlooks the location of the light switches and its interactions with the door opening. This leads to difficulty in gaining access to switch off the lighting when entering the space. Sometimes, maintenance manager add external plastic tranches to accommodate locating switches near access points (Alam, 2011).

EDP 8. Inadequate provision of the required illumination intensity

Each space has its required illumination intensity. Sometime, the required illumination intensity may not be achieved due to inadequate provisions of the necessary number of luminaries, suspending the luminaries at high locations and over decorating the luminaries (Chew, 2010; Alam, 2011).

EDP 9. Inability to reach high ceiling locations for the purpose of changing and cleaning fused light bulbs

Light bulbs have expected service life. In addition, they are prone to collect dust. Inability to reach the locations of fused light bulbs for the purpose of replacement and cleaning is a challenge for the maintenance staff (Alam, 2011; Ishak et al., 2007; Chew, 2010).

EDP 10. Inability to reach and maintain the main board of circuit breakers placed in invisible locations

In some instances, the main boards of circuit breakers are placed at invisible locations. Placing the main boards of circuit breakers in such locations is contrary to principle of providing for the ease of access to switch off the power supply during fire emergencies (Alam, 2011). Another maintenance concern is the placement of the main board of circuit breakers on external walls. Such locations facilitate for moisture ingress to the metal cabinets (Chew, 2010).

EDP 11. Convergence of low voltage cabling with high voltage cabling in the same duct

High voltage cabling of power should not be converged with low voltage cabling of communication, and internet cables in the same duct. If convergence of these cables is unavoidable, double insulation should be wrapped around low voltage cables to avoid the adversary effect of the high voltage power on communications and internet signals (Alam, 2011).

EDP 12. Total power and lighting cut-off when fire occurs (notification systems will not operate in other places)

When fire occurs, the total power and lighting might be cut-off in the buildings. Therefore, the notification systems will not operate to notify the building occupants. Moreover, the evacuation of occupants will be hindered due to lack of lighting provision (Alam, 2011).

EDP 13. Effect of lightning on electrical appliances (absences of grounding systems)

In buildings, grounding systems should be installed to prevent contact with dangerous voltage caused by lightning. Grounding systems should be included in the contract documents. They should be designed in accordance with the applicable codes and standards. The metal frames of all electrical equipment, machinery, lighting fixtures, enclosures, raceways, cable trays, outlet boxes, appliances and non-electric equipment in close proximity to electrical equipment should be grounded for the safety of occupants (Alam, 2011).

3.2.4 Mechanical Design Problems

This category includes seventeen mechanical design problems. They are referred to as (MDP 1 to MDP 18).

MDP 1. Inability to reach and maintain pipelines due to inappropriate layout of the fittings as well as horizontal runs of pipelines in slabs

Difficulties in locating and cleaning the pipelines are the main causes for corrosion. These difficulties occur as a result of inappropriate layout of pipelines fitting as well as the placement of pipelines within walls or floor slabs (Chew et al., 2008). Staining of pipeline fittings at corners and spalling of concrete are two major defects that could be avoided if a proper layout of pipeline network is developed (Chew et al., 2004). Supply pipelines that embedded in structural slabs should be avoided for the purposes of facilitating the provision of access to maintain them when need arises and consequent eliminating damage to other building systems (Hassanain, 2005; Chew, 2010).

MDP 2. Inability to distinguish between the pipes servicing different mechanical systems

In any building, there are many pipelines that service mechanical and fire protection systems. A significant challenge that occurs during the operation and maintenance stage is distinguishing between these different pipelines. Figure 3.14 illustrates the distribution of different pipelines (Chew, 2010; Abdel Mohsen, 2011).

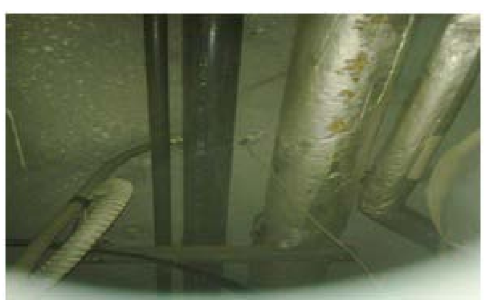

Figure 3.14: Different pipelines (The Author, 2012)

MDP 3. Water ponds on roofs due to the unavailability of drainage systems

Water ponds on roofs occur due to inadequate roof slopes as well as the unavailability of roof drains (Chew et al., 2004; De Silva and Ranasinghe, 2010). Water ponds lead to leakage which may damage the interior finish of buildings (Hassanain and Harkness, 1998). Figure 3.15illustrates the required minimum roof slope.

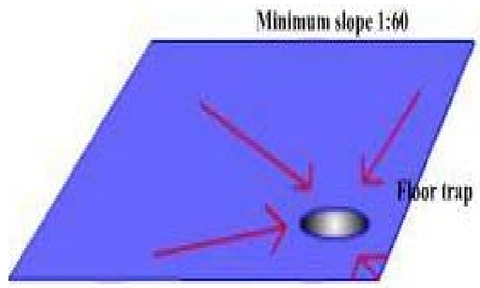

Figure 3.15: Minimum roof slope (Chew, 2010)

MDP 4. Slow sewer drainage due to insufficient diameter of stacks

Sewer vertical stacks and gutters should be provided with adequate diameter for proper drainage. Failure to provide the right diameter will lead to wastewater back up and eventually floods (Hassanain, 2005; Chew et al., 2008; Chew, 2010). The design of drainage system should provide for efficient rain water run-off removal from the structure (De Silva and Ranasinghe, 2010)

MDP 5. Inability to reach and maintain the sewer lines due to insufficient provision of manholes at corner points

The design and arrangement of sewer lines around the building parameter require that access is be provided for cleaning, monitoring and repair (Chew et al., 2004). The provision of manholes is required to provide access for underground drainage systems for maintenance and cleaning (De Silva, 2011; Chew et al., 2008). It is recommended to provide the sewer lines with manholes especially at corner points where dirt accumulation would cause blockage.

MDP 6. Propagation of foul odors due to the absence of ventilation vents

Lack of provision of vent stacks will cause dryness of the drains, hence, the propagation of foul odors (Chew et al., 2004; Hassanain, 2005; Chew et al., 2008). Additionally, induced siphonage resulting from the absence of vent stacks and self siphonage of improper sized discharge stacks are two possible causes for the propagation of foul odors in the buildings (Chew, 2010).

MDP 7. Leakage through floor trap due to improper selection of the types of the waterproofing membrane

Improper selection of the type of waterproofing membrane and improper detailing around floor drains are two main reasons that provides for water leakage and cyclic defect in interior finishes (De Silva and Ranasinghe, 2010; Chew, 2010; De Silva, 2011). Such defects could be alleviated through the proper selection of the type of waterproofing membrane along with the development of detailed construction drawing, as illustrated in Figure 3.16 (Chong and Low, 2006).

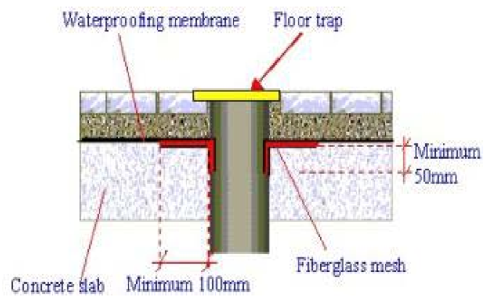

Figure 3.16: Detailed construction drawing for floor trap waterproofing (Chew, 2010)

MDP 8. Water leakage due to pipelines penetration through walls or floors

Penetrating floor levels for running pipeline minimizes the homogeneity of the waterproofing membrane and causes water leakages, as illustrated in Figure 3.17 (Chew, 2010). Proper detailing of the waterproofing membrane around pipe penetration provides for the construction of a monolithic entity (Chew, 2010; Chew et al., 2004).

Figure 3.17: Water leakages due to penetrations (Chew, 2010)

MDP 9. Noise and turbulent flow in pipelines due to insufficient diameter

Noise and turbulent flow in pipelines are two common defects in buildings. These defects are attributed to undersized pipeline diameters and inability to prevent water hammering. Water hammering occurs due to inadequate provision of anchor bolts at bends, and low size valves orifice that cause airlock (Chew et al., 2008; Chew, 2010).

MDP 10. Inadequate supply of water due to insufficient diameter of pipelines and head pressure

Inadequate water supply is a defect that occurs as a consequence of under sizing pipelines diameters and pumps. Sizing of water pumps should take into consideration pipe fittings and calculation of friction head loss (Chew, 2010; Abdel Mohsen, 2011).

MDP 11. Complete cut of water supply in the building due to the absence of shut off valves that enable part of the supply water to be closed when maintenance is required

Absence of shut-off valves causes complete water supply cut-off in the building. Each fixture in bathrooms and kitchens should be provided with values at cold and hot risers. Provision of valves at these locations facilitates for the ease of maintenance once required (Hassanain, 2005; Chew et al., 2008).

MDP 12. Corrosion of cast iron pipelines

Corrosion and degradation of cast iron pipelines in wet areas is a common design defect in buildings, as illustrated in . These cast iron pipelines could be underground or exposed (Hassanain, 2005; Chew et al., 2008). The rate of corrosion is accelerated when cast iron pipes are exposed to moisture and air (Chew, 2010).

Figure 3.18: pipelines corrosion (Chew, 2010)

MDP 13. Mould growth and stains on the façade due to the use of external drainage that penetrates the parapet

External drainage that penetrates the terrace's parapet will cause free falling of the wastewater on the façade. A thin film of moisture remains on the surface. This film of water traps dirt and organic particles from the atmosphere. With the dirt particles, moisture and sunlight, algae develop rapidly and form large patches of green stains on the façade (Hassanain and Harkness, 1998; Chew, 2010).

MDP 14. Fungi and mould growth around the bathtub edges due to the use improper type of sealants

The application of caulk sealant around the edges of the bathtub aims to prevent water seeping through the joints where the two edges of the bathtub meet the wall. With time, the caulk sealant deforms and erodes. Thus, it becomes moldy and defective. Cleaning the exposed line of caulk sealant with bleach prevents the subsequent growth of mold. Old caulk sealant has to be completely removed before the application of a replacement (Abdel Mohsen, 2011; McDermott, 2011).

MDP 15. Signs of cracks in wall plaster or tiles due to the use of suspended water closets

Suspended water closets may be selected to facilitate ease of floor cleaning. The disadvantage of suspended water closet is the development of cracks in the wall plaster or tiles. The development of cracks is attributed to the loads over the lifespan of the fixtures (Chew, 2010).

MDP 16. Absence of detection and notification systems at hazardous areas

Smoke detectors serve to detect the development of smoke at its early stages. Once smoke is detected, a visual-audible signal is sent to notification system via a circuit to alert the users of the building, and the fire brigade that a fire has been initiated (Hassanain and Saif, 2006).

MDP 17. Absence of appropriate fire suppression systems

There are four types of fire suppression systems. These systems include automatic sprinkler systems, standpipes and hose stations, chemical systems, and fire extinguishers. Sprinklers are considered to be the most effective means for the suppression of fire. Fontana et al, (1999) and Chew (2010) consider any building fitted with sprinklers to seldom suffer from severe fire damages.

3.2.5 HVAC design Problems

This category includes twelve heating, ventilating and air-conditioning (HVAC) design problems. They are referred to as (HDP 1 to HDP 12).

HDP 1. Inability to reach and maintain chillers, cooling towers and condensers due to the location of the mechanical plant

Designer should provide access to cooling towers, chillers, and condensers in order to allow for access to maintain the pumps, compressors, pipelines of chilled water (Hassanain and Harkness , 2000; Chew, 2010).

HDP 2. Signs of biological stains on false ceilings caused by leaky HVAC ducts

The development of condensation on HVAC ducts is attributed to the insufficient or damaged insulation wrapped around the ducts and the exposure of ducts to warm air infiltration. Water drops from either leaky HVAC ducts, or condensation occurrence on the fiber-based false ceilings creates favorable conditions for the development of biological stains, as illustrated in Figure 3.19 (Chew, 2010). It is recommended to avoid any horizontal runs of ducts above ceilings (Hassanain, 2005). However, this might be impossible in the case of HVAC ducts.

Figure 3.19: Biological stains on the false ceiling (Chew, 2010)

HDP 3. Moisture condensation on walls and glass due to inappropriate HVAC design temperature

Condensation occurs when the temperature of walls and glass drops below the dew point temperature. It is always desirable to prevent condensation on the surfaces because of its harmful effects (Ahmed, 2011). Condensation can be avoided if the indoor temperature is maintained as high as possible without compromising the comfort of occupants. Unfortunately, sometime the access for calibration sensors to fine tune the indoor temperature is blocked or not provided (Chew, 2010). Such design defect will result in the development of uncontrollable condensation.

HDP 4. Overheating of the building due to shutdown of chillers for maintenance or replacement of any parts

Sometime it is required to shutdown the chillers for either maintenance or replacement of defective parts. Prolonged shutdowns will result in overheating the building (Ahmed, 2011). It is recommended to provide a standby chiller to be used when any chiller is out of service for either maintenance or repair (Hassanain and Harkness, 2000).

HDP 5. Overcooling of the building due to temperature difference between the supply and return child water during winter

In winter, chillers work with low loads. This will result in insufficient difference between the temperature of the returned water from the evaporators in the air handing unit (AHU), and that of the leaving water from chillers. The result is that the building will become overcooled in order to maintain this temperature difference between supply and return chilled water (Hassanain and Harkness, 2000).

HDP 6. Inadequacy of the HVAC system to provide the required comfort zone temperature

HVAC system design should take into account the various sources of heat that affects the sizing of the chillers and air- handling units (AHUs) and the provision of comfortable zone temperature. Possible heat sources range from people's load, their clothes, appliances, the operation of lighting system to air infiltration (Hassanain and Harkness, 2000; Chew, 2010). Uncomfortable zone temperature may occur due to the adjacent locations of diffusers for supplied air and grilles for the returned air. Additionally, the unsuitable selection for diffusers' throw will lead to the provision of harmful and direct cold air that causes discomfort to the occupants (Chew, 2010).

HDP 7. Water spillage from HVAC units due to lack of condensation drainage systems

Condensation tray with floor drainage should be provided to HVAC units to avoid water spillage (Hassanain and Harkness, 2000). In locations where such drains are provided, spills of water from the HVAC system would still occur. This is mainly attributed to the under sizing of the drain traps which may be chocked with biological agents (Chew, 2010).

HDP 8. Inability to reach and maintain condensation pans location.

Gaining access to condensation pans for cleaning and removal of moisture is a design defect that could challenge the maintenance team. Failure to gain the require access will allow water return through condensation trays, thus, allowing toxic and microbial to breed. It is recommended to install stainless steel condensation pans for the purposes of longer service life and less maintenance requirements (Hassanain and Harkness, 2000).

HDP 9. Propagation of foul smells due to lack of provision of exhaust fans in kitchens and toilets

Kitchen and toilet should be provided with exhaust fans to avoid the propagation of foul odors, and to maintain these locations at negative pressure. It is recommended to provide kitchens and toilets with single air conditioning lines to avoid the intermixing of the return from these locations with the supply air to the other location (Hassanain and Harkness, 2000; Ahmed, 2011).

HDP 10. Poor indoor air quality that may cause infectious diseases and respiratory illnesses due to insufficient provision of fresh air

Poor indoor air quality in conditioned space develops due inadequate provision of fresh air. It is significant, wherever possible, to allow 100% fresh air flushing during some months of the year. This is useful in eliminating infectious diseases and respiratory illnesses (Hassanain and Harkness, 2000).

HDP 11. Static electricity due to insufficient humidification of admitted air to the building

Static electricity problem is attributed to uncontrolled humidity levels within the conditioned spaces. It is worth mentioning that high levels of moisture will support the growth of microbiological organisms, whereas low levels of moisture will lead to the development static electricity (Hassanain and Harkness, 2000).

HDP 12. Noisy air handling units due to lack of proper insulation

It is recommended to provide air handling units with acoustical insulation, vibration isolators. Moreover, they should be located away from the occupied spaces as much as possible (Chew, 2010).

3.3 DISCUSSION

In this chapter, a sixty six significant operation and maintenance problems were identified and described in detailed. These operation and maintenance problems are different in important. Also, the categories that included these problems are different in important too. Chapter five will provide and reflect the importance indexes of each category and problem.

CHAPTER 4

SET OF CONCERNS AND/OR DETAILS

4.1 BACKGROUND

This chapter presents the identification of the major set of concerns and/or details raised by the maintenance manager during the design development and review stages at different project design stages (i.e. 30%, 60% and 90%), which will have significant impacts on building maintainability in the future. A series of eighty five major concerns and/or details were identified. These set of concerns are effectively the feedback or the guidelines provided by the maintenance manger to the integrated design team in order to reduce the frequently and costly operation and maintenance problems. This feedback is derived from the accumulated experiences of operating and maintaining the technical systems of several types of buildings. The Identification of these concerns and/or details was carried out based on the identified operation and maintenance problems. These concerns aimed at being a remedial action for the identified problems facing the maintenance manager in any buildings. Also, the published literature was reviewed in order to understand the working mechanism of building systems and interviewed was held then developing the set of concerns and or details.

4.2 SET OF CONCERNS AND/OR DETAILS

The major set of concerns and/or details raised by the maintenance manager during the design development and review stages at different project design phases (i.e. 30%, 60%

and 90%) were classified under five categories, namely architectural major concerns and/or details, structural major concerns and/or details, electrical major concerns and/or details, mechanical major concerns and/or details, and HVAC major concerns and/or details. The following sub-sections present an identification of these various types of major concerns and/or details at different project design phases.

4.2.1 Architectural Major Concerns and/or Details

This category includes twenty two architectural major concerns and/or details at different project design phases (i.e. 30%, 60% and 90%). They are referred to as (AC).

4.2.1.1 Architectural at 30% of project design

The group of the architectural major concerns and/or details raised by the maintenance managers at 30% of project design included seven major concerns and/or details. They are referred to as (AC 1 to AC 7).

AC 1. Check that the design considers the orientation of the building and the wind load effect on the building envelops and interior spaces

AC 2. Check that the areas of the windows are appropriate for the prevailing climate and orientation of the building.

AC 3. Check that the dimensions of the doors and windows could accommodate movement of furniture.

AC 4. Check that the design provides consideration for access for the handicapped in terms provision of suitable parking, emergency egress routes, toilets, ramps for circulation, and suitable elevator panels.

AC 5. Check that the design takes into account the ability to accommodate future changes in the layout as demanded by clients.

AC 6. Check that all building materials are suitable for the local climate, especially for building envelopes.

AC 7. Check that the designer provides intermediate lobby between the outdoor and indoor areas to work as moisture and temperature trapping zone.

4.2.1.2 Architectural at 60% of project design

The group of the architectural major concerns and/or details raised by the maintenance managers at 60% of project design included five major concerns and/or details. They are referred to as (AC 8 to AC 12).

AC 8. Check that the architectural form of the building provides for ease of cleaning and maintenance of the fenestration.

AC 9. Check that basins of agriculture are located away from the facades to avoid dampness

AC 10. Check that the design provides the kitchens and bathrooms with windows.

AC 11. Check the provision of enough areas for exhaust and service shafts of kitchens and bathroom

AC 12. Check that the design provides access for fire fighting and egress routes.

4.2.1.3 Architectural at 90% of project design

The group of the architectural major concerns and/or details raised by the maintenance managers at 90% of project design included 10 major concerns and/or details. They are referred to as (AC 13 to AC 22).

AC 13. Check that all the materials specified by the design professionals are available at the markets at that time.

AC 14. Check that the design documents and specifications provides for exterior doors that swing outward.

AC 15. Check that the design of the building envelope provides for ease of replacement of systems and subsystems.

AC 16. Check that the specified type and the commercial brand of paint are reliable.

AC 17. Check that the specified type of tiles is wear and abrasion resistant.

AC 18. Check that the design provides for metal, wood, plastic or rubber walls edges around sharp corners.

AC 19. Check that the design and specification provides for a vapor barrier or retarder on the warm side of the wall to avoid internal condensation.

AC 20. Check that the design provides a complete set of drawings and details of thermal insulations for walls and roof.

AC 21. Check that the design provides for a detailing of waterproofing system to prevent leaks and hence deterioration of steel reinforcement.

AC 22. Check that the specified type and the commercial brand of waterproofing are reliable.

4.2.2 Structural Major Concerns and/or Details

This category includes eight structural major concerns and/or details at different project design phases (i.e. 30%, 60% and 90%). They are referred to as (SC).

4.2.2.1 Structural at 30% of project design

The group of the structural major concerns and/or details raised by the maintenance managers at 30% of project design included one major concern and/or detail. It is referred to as SC 1.

SC 1. Check that the design provides for expansion joints when the length of the building exceeds that length specified by the codes

4.2.2.2 Structural at 60% of project design

The group of the Structural major concerns and/or details raised by the maintenance managers at 60% of project design included two major concerns and/or details. They are referred to as (SC 2 to SC 3).

SC 2. Check that the results of the soils bearing capacity tests are taken into consideration in the design of the foundation system.

SC 3. Check that the design provides for the required strength, thickness, and fire resistance rating of building construction materials

4.2.2.3 Structural at 90% of project design

The group of the structural major concerns and/or details raised by the maintenance managers at 90% of project design included five major concerns and/or details. They are referred to as (SC 4 to SC 8).

SC 4. Check that the design provides for strict specifications for the procurement of concrete.

SC 5. Check that the specifications provide for adequate concrete cover for the steel reinforcement as specified by codes, and painting it to afford the bad weather conditions.

SC 6. Check that the specifications provide for a mesh between concrete brick joints and floor wall joints to avoid any future cracks.

SC 7. Check that the specification provide for a full soil compaction (if required) to avoid future settlement.

SC 8. Check that the specification provides for appropriate fireproofing and fire stopping materials in the building

4.2.3 Electrical Major Concerns and/or Details

This category includes fourteen electrical major concerns and/or details at 60% and 90% of project design phases only. They are referred to as (EC).

4.2.3.1 Electrical at 60% of project design

The group of the electrical major concerns and/or details raised by the maintenance managers at 60% of project design included twelve major concerns and/or details. They are referred to as (EC 1 to EC 12).

EC 1. Check that the main board of circuit breakers is placed in a safe and visible location.

EC2. Check that the design provides for a circuit breaker for each power plug in kitchens as well as for all room light switches.

EC 3. Check that the design provides for a sufficient number of luminaries to provide the required illumination intensity.

EC 4. Check that the design provides for lighting switches adjacent to access points.

EC 5. Check that the design provides for lighting in the elevator shaft.

EC 6. Check that the design provides for a sufficient number of power plugs to avoid the use of extension cords.

EC 7. Check that the design provides for a fan coil unit - with single point electrical connection box - for power supply and control.

EC 8. Check that the designer provides for clear cable management and identification.

EC 9. Check that the designer provides for communication and internet lines to the all spaces in the building.

EC 10. Check that the design provides for backup power supply, emergency lighting, and address wiring of fire notification systems, and detection systems.

EC 11. Check that the provided communication internet lines are away from power and lighting lines.

EC 12. Check that the design provides for grounding systems.

4.2.3.2 Electrical at 90% of project design

The group of the electrical major concerns and/or details raised by the maintenance managers at 90% of project design included two major concerns and/or details. They are referred to as (EC 13 to EC 14).

EC 13. Check that the specifications provide fluorescent ballasts that are electronic, high frequency, and of rapid start with no sound.

EC 14. Check that the specifications provides for the right diameter of cabling for the lighting system as well as for power plugs.

4.2.4 Mechanical Major Concerns and/or Details

This category includes twenty three mechanical major concerns and/or details at 60% and 90% of project design phases only. They are referred to as (MC).

4.2.4.1 Mechanical at 60% of project design

The group of the mechanical major concerns and/or details raised by the maintenance managers at 60% of project design included sixteen major concerns and/or details. They are referred to as (MC 1 to MC 16).

MC 1. Check that there are no pipelines penetrating the walls or the roof.

MC 2. Check that the design provides for a complete layout for all the pipelines.

MC 3. Check that all the supply pipelines are not running through the slabs.

MC 4. Check that there are no horizontal pipelines for supply or drainage run above the false ceiling.

MC 5. Check that all pipelines have the right diameter, especially the main riser of water supply and the drainage system.

MC 6. Check that the design provides for shutoff valves for each hot and cold riser, as well as for all branches.

MC 7. Check that the design provides for manholes for maintaining and cleaning the sewage system, especially at the corners.

MC 8. Check that the design provides for two different drainage lines of waste water; one for gray water and one for hand washing in order to store.

MC 9. Check that the design provides for sufficient numbers of drainage traps at the roof.

MC 10. Check that the design provides for cleanouts at both the ground and roof levels to filter any soil out from the storm water drains.

MC 11. Check that the design provides for ventilating stacks to maintain both pressure and siphonage, and avoid foul air entering the space.

MC 12. Check that there are no external drainage penetrates any parapets to avoid the development of moulds and stains on the façade**.**

MC 13. Check that the design provides for drains in mechanical plant where spillage might occur.

MC 14. Check that the design provides for supply pipelines for fire suppression purposes with appropriate pressure.

MC 15. Check that the design provides for means of escape from fire in buildings.

MC 16. Check that the design provides for appropriate systems for fire suppression, notification, and detection.

4.2.4.2 Mechanical at 90% of project design

The group of the mechanical major concerns and/or details raised by the maintenance managers at 90% of project design included seven major concerns and/or details. They are referred to as (MC 17 to MC 23).

MC 17. Check that the specified fixtures and fittings are to be supplied from a reliable manufacturer.

MC 18. Check the specified type of storage water tanks for potable water**.**

MC 19. Check that all pipelines and fittings used for the supply of clean water are lead-free.

MC 20. Avoid the specification of any unreinforced PVC at any exposed envelopes to solar radiation.

MC 21. Check that the specified elevators are procured from reliable manufacturer and are easy to upgrade.

MC 22. Check that the specifications provide for the sealant type that will be used in filling the expansion joints.

MC 23. Check that the specifications provides for a pressurization system that automatically activates by fire notification/ detection systems.

4.2.5 HVAC Major Concerns and/or Details

This category includes eighteen HVAC major concerns and/or details at different project design phases (i.e. 30%, 60% and 90%). They are referred to as (HC).

4.2.5.1 HVAC at 30% of project design

The group of the HVAC major concerns and/or details raised by the maintenance managers at 30% of project design included three major concerns and/or details. They are referred to as (HC 1.-HC 3).

HC 1. Check that the design provides access for reaching cooling towers, chillers, and condensers for maintenance.

HC 2. Check that access is provided to air handling unit rooms for ease of maintenance and replacement.

HC 3. Check that the cooling towers are located away from the adjacent buildings to eliminate background noise and emissions of mist.

4.2.5.2 HVAC at 60% of project design

The group of the HVAC major concerns and/or details raised by the maintenance managers at 60% of project design included eight major concerns and/or details. They are referred to as (HC 4 to SC 11).

HC 4. Check that the design provides for air conditioning supply to toilets and ablution areas. These locations should be maintained at negative pressure with properly sized exhaust/extract fans.

HC 5. Check that the design provides for more than one chiller, as chillers will operate more efficiently near the peak loads.

HC 6. Check that the design provides for a standby chiller that could be operated when other chillers are being serviced.

HC 7. Check that the design provides for dividing the HVAC ducting distribution through valves for ease of maintenance.

HC 8. Check that the design provides for adequate distance between the supply and return diffusers as well as the fresh air intake and exhaust air.

HC 9. Check that there is no intermixing of the exhaust air from kitchens and toilets with the fresh air intake from fresh air handling units.

HC 10. Check that the design provides for thermal and acoustical insulation for all air handling units and mechanical rooms**.**

HC 11. Check that the design provides for insulating all chilled water pipes to avoid any water leakages as well as condensation problems.

4.2.5.3 HVAC at 90% of project design

The group of the HVAC major concerns and/or details raised by the maintenance managers at 90% of project design included seven major concerns and/or details. They are referred to as (HC 12 to HC 18).

HC 12. Check that the design provides for a fan coil unit in the corridors at each floor level.

HC 13. Check that the design provides for a fresh air supply through the fan coil unit.

HC 14. Check that the design provides for expansion tanks in the chilled water hydronic circuit.

HC 15. Check that the specifications provides for using carbon filter in areas where transfer of odor and other contaminants is expected.

HC 16. Check that the design provides a complete set of drawings and details for duct distribution, riser diagram and chilled water supply and return ducts.

HC 17. Check that the design provides a complete set of drawings and details of the fire/smoke system interlocking with the HVAC system.

HC 18. Check that the design provides a complete set of drawings and details for the air handling units, fan coil units, exhaust fans, fire/smoke system and the cooling tower plant.

4.3 DISCUSSION

In this chapter an eighty five set of concerns and/or details were identified and classified under five categories namely, architectural major concerns and/or details, structural major concerns and/or details, electrical major concerns and/or details, mechanical major concerns and/or details, and HVAC major concerns and/or details. Each category included major concerns at different project design phases (i.e. 30%, 60%, and 90%) except the two categories electrical and mechanical major concerns included major concerns and/or details at 60% and 90% of project design phases. These major concerns and or details that raised by the maintenance manager are very significant for the integrated design team. Also, these concerns are very significant for any newly designer even if the maintenance manager is not involved during the design development and review stages. It will have significant impacts on building maintainability in the future.

Chapter five will provide and reflect the importance indexes of each category and set of concerns and/or details.

CHAPTER 5

DATA ANALYSIS AND RESULTS

5.1 BACKGROUND

The chapter presents the results of the assessment and data analysis of (1) The operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during the design development and review stages, and (2) The set of concerns and/or details raised by the maintenance manager during the design development and review stages which will have significant impacts on building maintainability in the future.

A sixty six operation and maintenance problems and eighty five major concerns and/or details at different design disciplines were identified as illustrated in chapter three and four respectively. These operations and maintenance problems and major concerns were assessed through developing, testing and administering of the questionnaire survey as described in the following:

5.2 DEVELOPMENT OF QUESTIONNAIRE SURVEY

A questionnaire survey (appendix-A) was developed and administered to a representative sample of maintenance departments of public Saudi Arabian Universities. The questionnaire survey consisted of two main parts:

- Part I of the questionnaire survey (appendix-A) consisted of five sections. These five sections were completed by the directors of the following maintenance department divisions: architectural, structural, electrical, mechanical, and HVAC. Each section consisted of two sub-sections as follows:

- ✓ **A**: This sub-section requires respondents to provide general information, the number of years of experience in working at the maintenance department, as well as to indicate their wish to receive a summary of the findings of the study.
- ✓ **B**: This sub-section contains the respondents assessment of:
    - **B1**: The identified sixty six operations and maintenance problems.
    - **B2**: The identified set of eighty five concerns and/or details.

- Part II of the questionnaire (Appendix-A) will serve the third objective in the thesis. It consisted of two sections. The two sections were completed by the maintenance division's managers of public Saudi Arabian universities. These two sections are as follows:

- ✓ **A:** This section contains four general questions about the respondent's name, contact information, number of years that the building stock has been in operation his experience as well as if interested in receiving a summary of the finding of the study.
- ✓ **B:** This section contains ten different questions on the current practice of the maintenance manager's involvement during the design development and review stages.

5.3 PILOT-TESTING OF THE QUESTIONNAIRE SURVEY

Before the questionnaire survey was finally distributed, a pilot-testing was carried out through conducting interviews with the in-house maintenance department managers of two universities, namely, King Fahd University of Petroleum and Minerals and Dammam University. The purpose of the pilot-testing was to:

- Test the adequacy of the questions.
- Identify locations of ambiguities.
- Incorporate additional possible factors.
- Review the adequacy of provided spaces for each question.
- Estimate the time needed for filling out the surveys.

5.4 DISTRIBUTION OF THE QUESTIONNAIRE SURVEY

The pilot-tested questionnaire survey was distributed to the maintenance departments of **13** public Saudi Arabian universities. Part I of the questionnaire survey aimed at assessing the importance of the identified **66** operation and maintenance problems and **85** major concerns and/or details by the maintenance department divisions (architecture, structural, electrical, mechanical and HVAC divisions). Part II aimed at investigating the current practices of the maintenance manager’s involvement during the design development and review stages in the public Saudi Arabian universities by the maintenance division’s managers.

All parts of the questionnaire survey were completed even by face to face interview or by telephone call. This step was carried out to ensure that the questionnaire parts were completed by the right respondents and to have reliable data.

The respondents to part I of the questionnaire survey were asked to rate the degree of importance of each of the identified **66** operation and maintenance problems, and **85** concerns and/or details by selecting one of the following evaluation terms, “**Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”.** The respondents to part II were asked to answer the questions related to the current practices of the maintenance manager’s involvement in the design development and review stages. Responses to the two parts of the questionnaire survey were collected from the maintenance departments of **12 out of 13** public Saudi Arabian universities.

5.5 DATA ANALYSIS FOR THE OPERATION AND MAINTENANCE PROBLEMS AND SET OF CONCERNS

This section presents the analysis of the data received from the respondents (maintenance departments divisions of **12** public Saudi Arabian universities) to part I of the questionnaire survey (appendix-A). The respondents to part I of the questionnaire survey were asked to rate the degree of importance of each of the identified **66** operation and maintenance problems, and **85** concerns and/or details by selecting one of the following “**Extremely Important**” with 4 points, “**Very Important**” with 3 points, “**Important**” with 2 points, “**Somewhat Important**” with one point and “**Not Important**” with zero points.

The importance index for each operation and maintenance problem, as well as the importance index for each concern raised by the maintenance manager has been calculated using equation 1.1 as included in chapter one.

$$\text{Importance Index (I)} = \frac{\sum_{i=0}^{4} a_i x_i}{4\sum_{i=0}^{4} x_i} \times 100\%$$

To reflect the scale of the respondents' answers to the questionnaire, the importance index is classified according to Table 5-1 as follows (Juaim and Hassanain, 2011):

Table 5-1: The importance index rate and classifications (Juaim and Hassanain, 2011)

Importance Index	Classification
0–<12.5%	Not Important
12.5–<37.5%	Somewhat Important
37.5–<62.5%	Important
62.5–<87.5%	Very Important
87.5–100%	Extremely Important

5.5.1 Architectural Operation and Maintenance Problems and Set of Concerns

This section in part I of the questionnaire survey (appendix-A) contained:

- A: General information about the architectural division's directors.
- B: Respondent's assessment of :
  - **B1**: The identified operation and maintenance problems that commonly emerge as a consequence of maintenance manager's lack involvement during the architectural design development and review stages

- **B2**: The identified set of concerns and/or details raised by the maintenance manager during the architectural design development and review stages.

5.5.1.1 Respondent’s general information

In this section, the directors of the architectural division in the maintenance departments of 12 public Saudi Arabian universities were asked to answer 3 questions about the respondent information, experience, interests in receiving summaries of the findings.

5.5.1.1.1 Respondents experience in maintenance department

In this question, the directors of the architectural division were asked to specify their work experience in the maintenance department by selecting one out of four ranges of years of experience as follows: “Less than 5 years”, “5 – 10 years”, “10 – 20 years” and “Over 20 years”. As illustrated in Figure 5.1, 25% of the respondents (3 out of 12 respondents) had less than 5 years experience, 33% of the respondents (4 respondents) had 5 – 10 years of experience, 25% of the respondents (3 respondents) had 10 – 20 years of experience, while 17% of the respondents (2 respondents) had more than 20 years experience of experience.

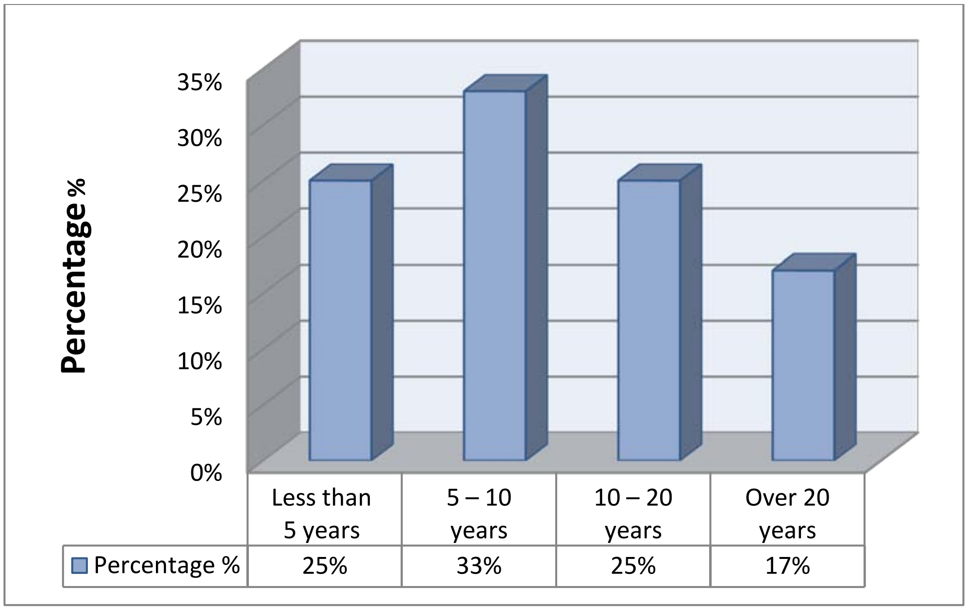

Figure 5.1: Directors' of the architectural division experience

5.5.1.2 Respondent's assessment

In this section, the directors of the architectural division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified architectural operation and maintenance problems and set of concerns and/or details.

A summary of the architectural division directors' responses to section I of part I of the questionnaire survey is illustrated in (Appendix-B).

5.5.1.2.1 Operation and maintenance problems

In this section, the directors of the architectural division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **16** operations and maintenance problems that commonly emerge as a consequence of maintenance manager's lack involvement during the architectural design development and review stages by selecting one of the following evaluation terms “Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”.

A summary of the assessed operation and maintenance problems’ importance index values and rate of importance is illustrated in Table 5-2

Table 5-2: Assessment of the architectural operation and maintenance problem

Operation and maintenance problems that commonly emerge as a consequence of the maintenance manager’s lack of involvement during the architectural design development and review stages		**Importance Index (%)**	**Rate of Importance**	**Rank**
1.	Inability to entirely reach and maintain the fenestration due to the architectural form of the building.	72.92	V.I.	7
2.	Insufficient availability of specific building materials in the market when replacement of the same is required.	75.00	V.I.	5
3.	Inappropriate selection and specification of specific building material for incorporation in the project.	72.92	V.I.	6
4.	Propagation of foul odor due the placement of kitchens and toilets in the direction of the prevailing wind.	56.25	I.	12
5.	Design and placement of large windows in building elevations facing the solar path.	54.17	I.	13
6.	Difficulty in moving the furniture and equipment within interior spaces due to the limited width and height of doors.	56.25	I.	11
7.	Wall edges that could chip due to impacts of loads and occupants.	75.00	V.I.	4
8.	Specification of low quality tiles that could be heavily stained or degraded due to heavy human traffic and weather condition.	77.08	V.I.	3

9.	Signs of stains and seepage due to improper rainwater drainage around windows.	79.17	V.I.	2
10.	Visibility of signs of stains and development of moulds due to inadequate means of ventilation (natural or mechanical or a combination of both).	52.08	I.	14
11.	Signs of stains on the building façade due to the different levels of moisture absorption of building materials.	58.33	I.	10
12.	Moisture and vapors traveling from wet to dry faces.	62.50	V.I.	9
13.	Plaster decay on external wall surface due to dampness.	68.75	V.I.	8
14.	Specification of dark color paint as an exterior finish in hot, arid and dusty regions.	39.58	I.	16
15.	Paint peeling, flaking, blistering, biological attack and efflorescence.	50.00	I.	15
16	Inability to maintain vertical risers due to the limited areas of the service shafts.	91.67	E.I.	1
	Average Importance Index %	**65.10**	**V.I.**	**-**

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.5.1.2.2 Set of concerns and/or details

In this section, the directors of the architectural division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **22** set of concerns and/or details raised by the maintenance managers during the architectural design development and review stages at different project design phases (i.e. 30%, 60% and 90%) by selecting one of the following evaluation terms “Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”

A summary of the assessed set of concerns and/or details’ importance index values and rate of importance is illustrated in Table 5-3

Table 5-3: Assessment of the architectural set of concerns and/or details

Major Concerns and/or details raised by the maintenance manager during the architectural design development and review stages		Importance Index (%)	Rate of Importance	Rank
A. At 30% of the project design				
1.	Check that the design considers the orientation of the building and the wind load effect on the building envelops and interior spaces.	54.17	I.	7
2.	Check that the areas of the windows are appropriate for the prevailing climate and orientation of the building.	56.25	I.	6
3.	Check that the dimensions of the doors and windows could accommodate movement of furniture.	58.33	I.	5
4.	Check that the design provides consideration for access for the handicapped in terms provision of suitable parking, emergency egress routes, toilets, ramps for circulation, and suitable elevator panels.	95.83	E.I.	1
5.	Check that the design takes into account the ability to accommodate future changes in the layout as demanded by clients.	79.17	V.I.	2
6.	Check that all building materials are suitable for the local climate, especially for building envelopes.	64.58	V.I.	3
7.	Check that the designer provides intermediate lobby between the outdoor and indoor areas to work as moisture and temperature trapping zone.	60.42	V.I.	4
	Average Importance Index %	**66.96**	**V.I.**	**-**
B. At 60% of the project design				
1.	Check that the architectural form of the building provides for ease of cleaning and maintenance of the fenestration.	60.42	I.	4
2.	Check that basins of agriculture are located away from the facades to avoid dampness	81.25	V.I.	2
3.	Check that the design provides the kitchens and bathrooms with windows.	50.00	I.	5
4.	Check the provision of enough areas for exhaust and service shafts of kitchens and bathroom	66.67	V.I.	3
5.	Check that the design provides access for fire fighting and egress routes.	95.83	E.I.	1
	Average Importance Index %	**70.83**	**V.I.**	**-**

	C. At 90% of the project design			
1.	Check that all the materials specified by the design professionals are available at the markets at that time.	85.42	V.I.	1
2.	Check that the design documents and specifications provides for exterior doors that swing outward.	79.17	V.I.	2
3.	Check that the design of the building envelope provides for ease of replacement of systems and subsystems.	54.17	I.	10
4.	Check that the specified type and the commercial brand of paint is reliable.	70.83	V.I.	7
5.	Check that the specified type of tiles is wear and abrasion resistant.	75.00	V.I.	4
6.	Check that the design provides for metal, wood, plastic or rubber walls edges around sharp corners.	72.92	V.I.	5
7.	Check that the design and specification provides for a vapor barrier or retarder on the warm side of the wall to avoid internal condensation.	58.33	I.	9
8.	Check that the design provides a complete set of drawings and details of thermal insulations for walls and roof.	77.08	V.I.	3
9.	Check that the design provides for a detailing of waterproofing system to prevent leaks and hence deterioration of steel reinforcement.	72.92	V.I.	6
10.	Check that the specified type and the commercial brand of waterproofing are reliable.	60.42	I.	8
	Average Importance Index %	**70.63**	**V.I.**	**-**

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.5.2 Structural Operation and Maintenance Problems and Set of Concerns

This section in part I of the questionnaire survey (appendix-A) contained:

- A: General information about the structural division's directors.
- B: Respondent's assessment of :
    - **B1**: The identified operation and maintenance problems that commonly emerge as a consequence of maintenance manager's lack involvement during the structural design development and review stages

- **B2**: The identified set of concerns and/or details raised by the maintenance manager during the structural design development and review stages.

5.5.2.1 Respondent’s general information

In this section, the directors of the structural division in the maintenance departments of 12 public Saudi Arabian universities were asked to answer 3 questions about the respondent information, experience, interests in receiving summaries of the findings.

5.5.2.1.1 Respondent Experience in Maintenance Department

In this question number, the directors of the structural division were asked to specify their work experience in the maintenance department by selecting one out of four ranges of years of experience as follows: “Less than 5 years”, “5 – 10 years”, “10 – 20 years” and “Over 20 years”. As illustrated in Figure 5.2, 17% of the respondents (2 out of 12 respondents) had less than 5 years experience., 33% of the respondents (4 respondents) had 5 – 10 years of experience, 25% of the respondents (3 respondents) had 10 – 20 years of experience, while 25% of the respondents (3 respondents) had more than 20 years experience of experience.

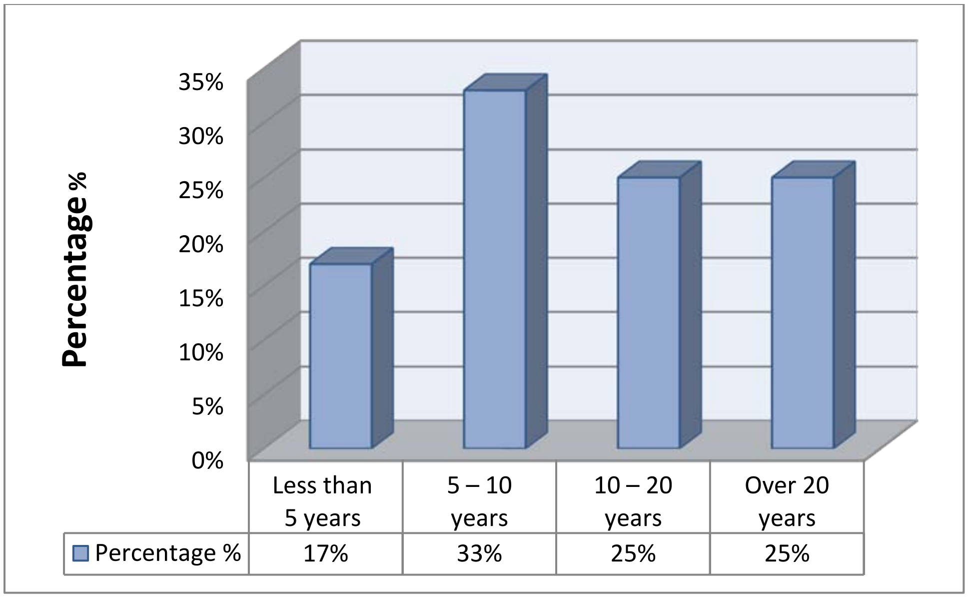

Figure 5.2: Directors' of the structural division experience

5.5.2.2 Respondent's assessment

In this section, the directors of the structural division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified structural operation and maintenance problems and set of concerns and/or details.

A summary of the structural division directors' responses to section II of part I of the questionnaire survey is illustrated in (Appendix-B).

5.5.2.2.1 Operation and maintenance problems

In this section, the directors of the structural division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **8** operations and maintenance problems that commonly emerge as a consequence of maintenance manager's lack involvement during the structural design development and review stages by selecting one of the following evaluation terms “Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”.

A summary of the assessed operation and maintenance problems’ importance index values and rate of importance is illustrated in Table 5-4.

Table 5-4: Assessment of the structural operation and maintenance problems

Operation and maintenance problems that commonly emerge as a consequence of the maintenance manager’s lack of involvement during the structural design development and review stages		**Importance Index (%)**	**Rate of Importance**	**Rank**
1.	Signs of cracks around columns and beams due to inadequate structural design.	54.17	I.	8
2.	Cracks in floor slabs, walls, and tiles due to differential settlement.	68.75	V.I.	4
3.	Corrosion of steel reinforcement bars due to Insufficient concrete cover.	70.83	V.I.	3
4.	Tile deponding, adhesive failure, cracks and fraction at weak points due to expansion and contraction stresses.	66.67	V.I.	5
5.	Moisture and dirt infiltration through expansion joints due to inefficient filling materials and sealant.	66.67	V.I.	6
6.	Sign of moisture penetration in the basement at beam-wall joints, walls, and ceiling-wall joints due to insufficient waterproofing and insulation.	60.42	I.	7
7.	Damage to underground pipelines due to the settlement of soil and foundations.	72.92	V.I.	2
8.	Plaster crack between concrete brick joints and wall-floor joints.	77.08	V.I.	1
Average Importance Index %		**67.19**	**V.I.**	**-**

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.5.2.2.2 Set of concerns and/or details

In this section, the directors of the structural division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **8** set of concerns and/or details raised by the maintenance manager during structural design development and review stages at different project design phases (i.e. 30%, 60%, 90%) by selecting one of the following evaluation terms “Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”

A summary of the assessed set of concerns and/or details’ importance index values and rate of importance is illustrated in Table 5-5.

Table 5-5: Assessment of the structural set of concerns and/or details

	Major Concerns and/or details raised by the maintenance manager during the structural design development and review stages	**Importance Index (%)**	**Rate of Importance**	**Rank**
A. At 30% of the project design				
1.	Check that the design provides for expansion joints when the length of the building exceeds that length specified by the codes	81.25	V.I.	1
	Average Importance Index %	**81.25**	**V.I.**	**-**
B. At 60% of the project design				
1.	Check that the results of the soils bearing capacity tests are taken into consideration in the design of the foundation system.	79.17	V.I.	1
2.	Check that the design provides for the required strength, thickness, and fire resistance rating of building construction materials	68.75	V.I.	2
	Average Importance Index %	**73.96**	**V.I.**	**-**

C. At 90% of the project design				
1.	Check that the design provides for strict specifications for the procurement of concrete.	66.67	V.I.	5
2.	Check that the specifications provide for adequate concrete cover for the steel reinforcement as specified by codes, and painting it to afford the bad weather conditions.	87.50	E.I.	2
3.	Check that the specifications provide for a mesh between concrete brick joints and floor wall joints to avoid any future cracks.	85.42	V.I.	3
4.	Check that the specification provide for a full soil compaction (if required) to avoid future settlement.	68.75	V.I.	4
5.	Check that the specification provides for appropriate fireproofing and fire stopping materials in the building.	91.67	E.I.	1
	Average Importance Index %	**80.00**	**V.I.**	**-**

E.I Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.5.3 Electrical Operation and Maintenance Problems and Set of Concerns

This section in part I of the questionnaire survey (appendix-A) contained:

- A: General information about the electrical division's directors.
- B: Respondent's assessment of :
    - **B1**: The identified operation and maintenance problems that commonly emerge as a consequence of maintenance manager's lack involvement during the electrical design development and review stages
    - **B2**: The identified set of concerns and/or details raised by the maintenance manager during the electrical design development and review stages.

5.5.3.1 Respondent's general information

In this section, the directors of electrical division in the maintenance departments of 12 public Saudi Arabian universities were asked to answer 3 questions about the respondent information, experience, interests in receiving summaries of the findings.

5.5.3.1.1 Respondent experience in maintenance department

In this question number, the directors of electrical division were asked to specify their work experience in the maintenance department by selecting one out of four ranges of years of experience as follows: “Less than 5 years”, “5 – 10 years”, “10 – 20 years” and “Over 20 years”. As illustrated in Figure 5.3, 9% of the respondents (1 out of 12 respondents) had less than 5 years experience., 33% of the respondents (4 respondents) had 5 – 10 years of experience, 33% of the respondents (4 respondents) had 10 – 20 years of experience, while 25% of the respondents (3 respondents) had more than 20 years experience of experience.

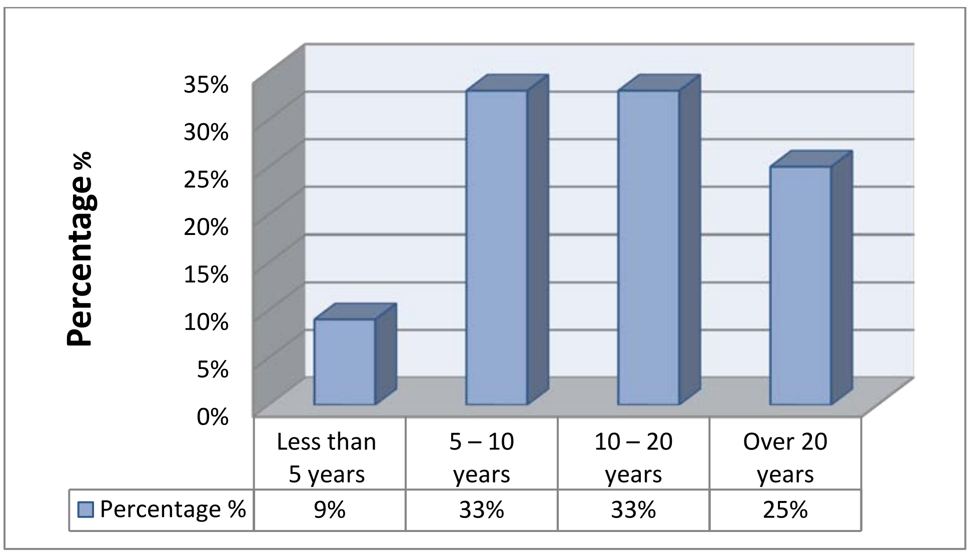

Figure 5.3: Directors’ of the electrical division experience

5.5.3.2 Respondent’s assessment

In this section, the directors of the electrical division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified electrical operation and maintenance problems and set of concerns and/or details.

A summary of the electrical division directors' responses to section III of part I of the questionnaire survey is illustrated in (Appendix-B).

5.5.3.2.1 Operation and maintenance problems

In this section, the directors of the electrical division in maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **13** operations and maintenance problems that commonly emerge as a consequence of maintenance manager's lack involvement during the electrical design development and review stages by selecting one of the following evaluation terms "Extremely Important", "Very Important", "Important", "Somewhat Important" and "Not Important".

A summary of the assessed operation and maintenance problems' importance index values and rate of importance is illustrated in Table 5-6.

Table 5-6: Assessment of the electrical operation and maintenance problems

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during the electrical design development and review stages (power, lighting, and communication cables)		Importance Index (%)	Rate of Importance	Rank
1.	Short circuits due to overload occurrence in plug points.	83.33	V.I.	3
2.	Insufficient number and distribution of plugs points.	70.83	V.I.	9
3.	Total power cut from one fault.	72.92	V.I.	8
4.	Exposed cabling and loose connections	89.58	E.I.	1
5.	Exposed Plugs at open and wet areas.	85.42	V.I.	2
6.	Flickering and blinking of fluorescent lamps.	64.58	V.I.	12

7.	Placement of light switches far away from access points.	66.67	V.I.	11
8.	Inadequate provision of the required illumination intensity.	68.75	V.I.	10
9.	Inability to reach high ceiling locations for the purpose of changing or cleaning fused light bulbs.	58.33	I.	13
10.	Inability to reach and maintain the main board of circuit breakers placed in invisible locations.	72.92	V.I.	7
11.	Convergence low voltage cabling with high voltage cabling in the same ducts	75.00	V.I.	6
12.	Total power and lighting cutoff when fire occurs (Notification systems will not operate in other places)	77.08	V.I.	5
13.	Effect of lightning on electrical appliances. (absence of grounding systems)	79.17	V.I.	4
	Average Importance Index %	**74.20**	**V.I.**	**-**

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.5.3.2.2 Set of concerns and/or details

In this section, the directors of the electrical division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **14** set of concerns and/or details raised by the maintenance manager during the electrical design development and review stages at 60% of project design phase and 90%of project design phase by selecting one of the following evaluation terms “Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”

A summary of the assessed set of concerns’ and/or details’ importance index values and rate of importance is illustrated in Table 5 7.

Table 5-7: Assessment of the electrical set of concerns and/or details

Major Concerns and/or details raised by the maintenance manager during the electrical design development and review stages (power, lighting, and communication cables)		Importance Index (%)	Rate of Importance	Rank
A. At 60% of the project design				
1.	Check that the main board of circuit breakers is placed in a safe and visible location.	87.50	E.I.	1
2.	Check that the design provides for a circuit breaker for each power plug in kitchens as well as for all room light switches.	83.33	V.I.	3
3.	Check that the design provides for a sufficient number of luminaries to provide the required illumination intensity.	75.00	V.I.	7
4.	Check that the design provides for lighting switches adjacent to access points.	77.08	V.I.	5
5.	Check that the design provides for lighting in the elevator shaft.	60.42	I.	12
6.	Check that the design provides for a sufficient number of power plugs to avoid the use of extension cords.	81.25	V.I.	4
7.	Check that the design provides for a fan coil unit - with single point electrical connection box - for power supply and control.	68.75	V.I.	10
8.	Check that the designer provides for clear cable management and identification	72.92	V.I.	8
9.	Check that the designer provides for communication and internet lines to the all spaces in the building	66.67	V.I.	11
10.	Check that the design provides for backup power supply, emergency lighting, and address wiring of fire notification systems, and detection systems	77.08	V.I.	6
11.	Check that the provided communication internet lines are away from power and lighting lines	70.83	V.I.	9
12.	Check that the design provides for grounding systems.	85.42	V.I.	2
	Average Importance Index %	**75.52**	**V.I.**	**-**
B. At 90% of the project design				
1.	Check that the specifications provide fluorescent ballasts that are electronic, high frequency, and of rapid start with no sound.	77.08	V.I.	2
2.	Check that the specifications provides for the right diameter of cabling for the lighting system as well as for power plugs.	93.75	E.I.	1
	Average Importance Index %	**85.42**	**V.I.**	**-**

5.5.4 Mechanical Operation and Maintenance Problems and Set of Concerns

This section in part I of the questionnaire survey (appendix-A) contained:

- A: General information about the mechanical division's directors.
- B: Respondent's assessment of :
  - **B1:** The identified operation and maintenance problems that commonly emerge as a consequence of maintenance manager's lack involvement during the mechanical design development and review stages
  - **B2:** The identified set of concerns and/or details raised by the maintenance manager during the mechanical design development and review stages.

5.5.4.1 Respondent's general information

In this section, the directors of the mechanical division in maintenance departments of 12 public Saudi Arabian universities were asked to answer 3 questions about the respondent information, experience, interests in receiving summaries of the findings

5.5.4.1.1 Respondent experience in maintenance department

In this question number, the directors of the mechanical division were asked to specify their work experience in the maintenance department by selecting one out of four ranges of years of experience as follows: "Less than 5 years", "5 – 10 years", "10 – 20 years" and "Over 20 years". ". As illustrated in Figure 5.4, 9% of the respondents (1 out of 12 respondents) had less than 5 years experience., 17% of the respondents (2 respondents) had 5 – 10 years of experience, 33% of the respondents (4 respondents) had 10 – 20 years of experience, while 42% of the respondents (5 respondents) had more than 20 years experience of experience.

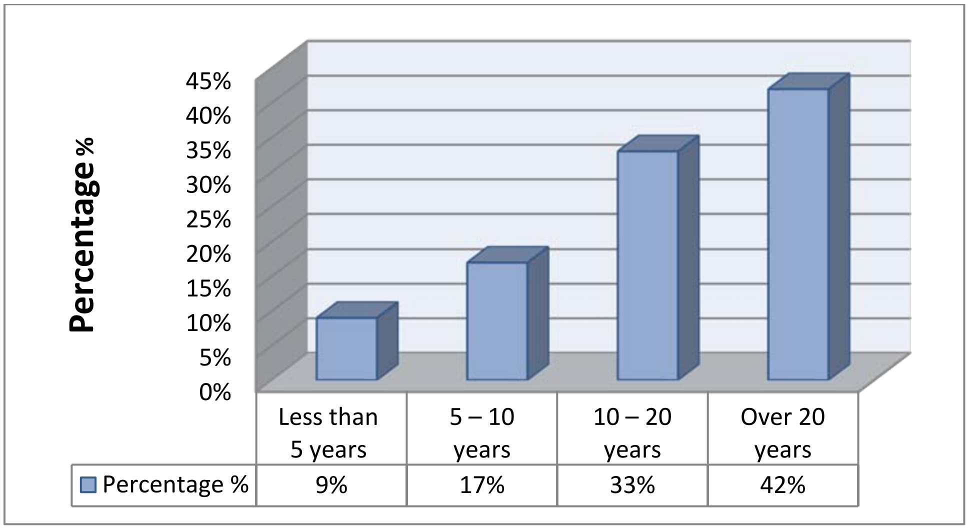

Figure 5.4:Directors' of the mechanical division experience

5.5.4.2 Respondent's assessment

In this section, the directors of the mechanical division in the maintenance department of 12 public Saudi Arabian universities were asked to assess the identified mechanical operation and maintenance problems and set of concerns and/or details.

A summary of the mechanical division directors' responses to section IV of part I of the questionnaire survey is illustrated in (Appendix-B).

5.5.4.2.1 Operation and maintenance problems

In this section, the directors of the mechanical division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **17** operations and maintenance problems that commonly emerge as a consequence of maintenance manager's lack involvement during mechanical design development and review stages by selecting one of the following evaluation terms "Extremely Important", "Very Important", "Important", "Somewhat Important" and "Not Important".

A summary of the assessed operation and maintenance problems' importance index values and rate of importance is illustrated in Table 5-8.

Table 5-8: Assessment of the mechanical operation and maintenance problems

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during the mechanical design development and review stages (water supply system, sewage system and fire system)		Importance Index (%)	Rate of Importance	Rank
1.	Inability to reach and maintain pipelines due to inappropriate layout of the fitting as well as horizontal runs of pipeline in slabs.	89.58	E.I.	3
2.	Inability to distinguish between the pipes servicing the different mechanical systems.	75.00	V.I.	11
3.	Water ponds on roofs due to the unavailability of drainage systems.	77.08	V.I.	9
4.	Slow sewer drainage due to insufficient diameter of stacks.	72.92	V.I.	12
5.	Inability to reach and maintain the sewer lines due to insufficient provision of manholes at corner points.	83.33	V.I.	5
6.	Propagation of foul odors due to the absence of ventilation vents.	81.25	V.I.	7
7.	Leakage through floor trap due to improper selection of the types of the waterproofing membrane.	70.83	V.I.	13
8.	Water leakage due to pipelines penetration through walls or floors.	79.17	V.I.	8
9.	Noise and turbulent flow in pipelines due to insufficient diameter.	68.75	V.I.	14
10.	Inadequate supply of water due to the insufficient diameter of pipelines and head pressure.	62.50	V.I.	10
11.	Complete cut of water supply in the building due to the absence of shut off valves that enable part of supply water to be closed when maintenance is required.	87.50	E.I.	4
12.	Corrosion of cast iron pipelines.	81.25	V.I.	6
13.	Moulds growth and stains on the façade due to the use of external drainage that penetrates the parapet.	75.00	V.I.	10
14.	Fungi and mould growth around the bathtub edges due to the use improper type of sealants.	66.67	V.I.	15
15.	Signs of cracks in wall plaster or tiles due to the use of suspended water closets.	64.58	V.I.	16
16.	Absence of detection and notification systems at hazardous areas.	97.92	E.I.	1
17.	Absence of appropriate fire suppression systems.	89.58	E.I.	2
	Average Importance Index %	**77.82**	**V.I.**	**-**

5.5.4.2.2 Set of concerns and/or details

In this section, the directors of the mechanical division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **23** set of concerns and/or details raised by the maintenance manager during the mechanical design development and review stages at 60% of project design phase and 90%of project design phase by selecting one of the following evaluation terms “Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”

A summary of the assessed set of concerns and/or details’ importance index values and rate of importance is illustrated in Table 5-9

Table 5-9: Assessment of the mechanical set of concerns and/or details

Major Concerns and/or details raised by the maintenance manager during the mechanical design development and review stages (water supply system, sewage system and fire system)		Importance Index (%)	Rate of Importance	Rank
A. At 60% of the project design				
1.	Check that there are no pipelines penetrating the walls or the roof.	87.50	E.I.	4
2.	Check that the design provides for a complete layout for all the pipelines.	81.25	V.I.	9
3.	Check that all the supply pipelines are not running through the slabs.	87.50	E.I.	5
4.	Check that there are no horizontal pipelines for supply or drainage run above the false ceiling.	83.33	V.I.	7
5.	Check that all pipelines have the right diameter, especially the main riser of water supply and the drainage system.	89.58	E.I.	3
6.	Check that the design provides for shutoff valves for each hot and cold riser, as well as for all branches.	95.83	E.I.	1

7.	Check that the design provides for manholes for maintaining and cleaning the sewage system, especially at the corners.	85.42	V.I.	6
8.	Check that the design provides for two different drainage lines of waste water; one for gray water and one for hand washing in order to store.	68.75	V.I.	13
9.	Check that the design provides for sufficient numbers of drainage traps at the roof.	72.92	V.I.	12
10.	Check that the design provides for cleanouts at both the ground and roof levels to filter any soil out from the storm water drains.	58.33	I.	15
11.	Check that the design provides for ventilating stacks to maintain both pressure and siphonage, and avoid foul air entering the space.	79.17	V.I.	10
12.	Check that there are no external drainage penetrates any parapets to avoid the development of moulds and stains on the façade.	56.25	I.	16
13.	Check that the design provides for drains in mechanical plant where spillage might occur.	64.58	V.I.	14
14.	Check that the design provides for supply pipelines for fire suppression purposes with appropriate pressure.	83.33	V.I.	8
15.	Check that the design provides for means of escape from fire in buildings.	75.00	V.I.	11
16.	Check that the design provides for appropriate systems for fire suppression, notification, and detection.	93.75	E.I.	2
	Average Importance Index %	**78.91**	**V.I.**	**-**
B. At 90% of the project design				
1.	Check that the specified fixtures and fittings are to be supplied from a reliable manufacturer.	72.92	V.I.	5
2.	Check the specified type of storage water tanks for potable water.	58.33	I.	7
3.	Check that all pipelines and fittings used for the supply of clean water are lead-free.	70.83	V.I.	6
4.	Avoid the specification of any unreinforced PVC at any exposed envelopes to solar radiation.	81.25	V.I.	2
5.	Check that the specified elevators are procured from reliable manufacturer and are easy to upgrade.	79.17	V.I.	3
6.	Check that the specifications provide for the sealant type that will be used in filling the expansion joints	83.33	V.I.	1
7.	Check that the specifications provides for a pressurization system that automatically activates by fire notification/ detection systems.	77.08	V.I.	4
	Average Importance Index %	**74.70**	**V.I.**	**-**

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.5.5 HVAC Operation and Maintenance Problems and Set of Concerns

This section in part I of the questionnaire survey (appendix-A) contained:

- A: General information about the HVAC division's directors.
- B: Respondent's assessment of :
    - **B1**: The identified operation and maintenance problems that commonly emerge as a consequence of maintenance manager's lack involvement during the HVAC design development and review stages
    - **B2:** The identified set of concerns and/or details raised by the maintenance manager during the HVAC design development and review stages.

5.5.5.1 Respondent's general information

In this section, the directors of the HVAC division in maintenance department of 12 public Saudi Arabian universities were asked to answer 3 questions about the respondent information, experience, interests in receiving summaries of the findings.

5.5.5.1.1 Respondent experience in maintenance department

In this question number, the directors of the HVAC division were asked to specify their work experience in the maintenance department by selecting one out of four ranges of years of experience as follows: "Less than 5 years", "5 – 10 years", "10 – 20 years" and "Over 20 years". As illustrated in Figure 5.5, 0% of the respondents (No one out of 12 respondents) had less than 5 years experience., 25% of the respondents (3 respondents) had 5 – 10 years of experience, 33% of the respondents (4 respondents) had 10 – 20 years of experience, while 42% of the respondents (5 respondents) had more than 20 years experience of experience.

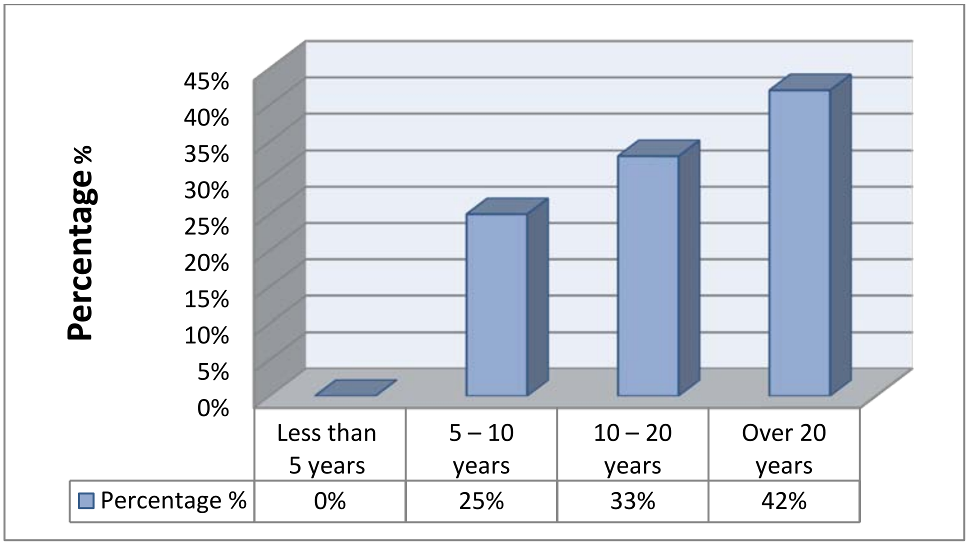

Figure 5.5: Directors' of the HVAC division experience

5.5.5.2 Respondent's assessment

In this section, the directors of the HVAC division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified HVAC operation and maintenance problems and set of concerns and/or details.

A summary of the HVAC division directors' responses to section V of part I of the questionnaire survey is illustrated in (Appendix-B)

5.5.5.2.1 Operation and maintenance problems

In this section, the directors of the HVAC division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **12** operations and maintenance problems that commonly emerge as a consequence of maintenance manager’s lack involvement during the HVAC design development and review stages by selecting one of the following evaluation terms “Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”.

A summary of the assessed operation and maintenance problems’ importance index values and rate of importance is illustrated in Table 5-10.

Table 5-10: Assessment of the HVAC operation and maintenance problems

	Operation and maintenance problems that are attributed to the maintenance manager’s lack of involvement during the HVAC design development and review stages	**Importance Index (%)**	**Rate of Importance**	**Rank**
1.	Inability to reach and maintenance chillers, cooling towers and condenser due to the location of mechanical plant.	77.08	V.I.	7
2.	Signs of biological stains on false ceiling caused by leaky HVAC ducts.	75.00	V.I.	8
3.	Moisture condensation on walls and glass due to inappropriate HVAC design temperature.	70.83	V.I.	10
4.	Overheating of the building due to shut down of chillers for maintenance or replacement of any parts.	83.33	V.I.	4
5.	Overcooling of the building due to temperature difference between the supply and return child water during winter.	66.67	V.I.	11
6.	Inadequacy of the HVAC system to provide the required comfort zone temperature.	87.50	E.I.	1
7.	Water spillage from HVAC units due to lack of condensation drainage systems.	81.25	V.I.	5
8.	Inability to reach and maintain condensation pans location	72.92	V.I.	9
9.	Propagation of foul smells due to lack of provision of exhaust fans in kitchens and toilets.	83.33	V.I.	3

10.	Poor indoor air quality that may cause infectious diseases and respiratory illnesses due to insufficient provision of fresh air.	85.42	V.I.	2
11.	Static electricity due to insufficient humidification of admitted air to the building.	56.25	I.	12
12.	Noisy air handling units due to lack of proper insulation.	79.17	V.I.	6
	Average Importance Index %	**76.56**	**V.I.**	**-**

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.5.5.2.2 Set of concerns and/or details

In this section, the directors of the HVAC division in the maintenance departments of 12 public Saudi Arabian universities were asked to assess the identified **18** set of concerns and/or details raised by the maintenance manager during the HVAC design development and review stage at different project design phases (i.e. 30%, 60%, 90%) by selecting one of the following evaluation terms “Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”

A summary of the assessed set of concerns and/or details’ importance index values and rate of importance is illustrated in Table 5-11.

Table 5-11: Assessment of the HVAC set of concerns and/or details

Major Concerns and/or details raised by the maintenance manager during the HVAC design development and review stages		Importance Index (%)	Rate of Importance	Rank
A. At 30% of the project design				
1.	Check that the design provides access for reaching cooling towers, chillers, and condensers for maintenance.	79.17	V.I.	2
2.	Check that access is provided to air handling unit rooms for ease of maintenance and replacement.	77.08	V.I.	3
3.	Check that the cooling towers are located away from the adjacent buildings to eliminate background noise and emissions of mist.	81.25	V.I.	1
	Average Importance Index %	**79.17**	**V.I.**	**-**
B. At 60% of the project design				
1.	Check that the design provides for air conditioning supply to toilets and ablution areas. These locations should be maintained at negative pressure with properly sized exhaust/extract fans.	95.83	E.I.	1
2.	Check that the design provides for more than one chiller, as chillers will operate more efficiently near the peak loads.	85.42	V.I.	6
3.	Check that the design provides for a standby chiller that could be operated when other chillers are being serviced.	79.17	V.I.	8
4.	Check that the design provides for dividing the HVAC ducting distribution through valves for ease of maintenance.	87.50	E.I.	5
5.	Check that the design provides for adequate distance between supply and return diffusers as well as the fresh air intake and exhaust air.	89.58	E.I.	4
6.	Check that there is no intermixing of the exhaust air from kitchens and toilets with the fresh air intake from fresh air handling units.	93.75	E.I.	2
7.	Check that the design provides for thermal and acoustical insulation for all air handling units and mechanical rooms.	81.25	V.I.	7
8.	Check that the design provides for insulating all chilled water pipes to avoid any water leakages as well as condensation problems.	91.67	E.I.	3
	Average Importance Index %	**88.02**	**E.I.**	**-**

C. At 90% of the project design				
1.	Check that the design provides for a fan coil unit in the corridors at each floor level.	68.75	V.I.	7
2.	Check that the design provides for a fresh air supply through the fan coil unit.	77.08	V.I.	4
3.	Check that the design provides for expansion tanks in the chilled water hydronic circuit.	72.92	V.I.	5
4.	Check that the specifications provides for using carbon filter in areas where transfer of odor and other contaminants is expected.	70.83	V.I.	6
5.	Check that the design provides a complete set of drawings and details for duct distribution, riser diagram and chilled water supply and return ducts.	89.58	E.I.	3
6.	Check that the design provides a complete set of drawings and details of the fire/smoke system interlocking with the HVAC system.	93.75	E.I.	1
7.	Check that the design provides a complete set of drawings and details for the air handling units, fan coil units, exhaust fans, fire/smoke system and the cooling tower plant.	91.67	E.I.	2
Average Importance Index %		**80.65**	**V.I.**	**-**

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.6 RANKS OF OPERATION AND MAINTENNACE PROBLEMS CATEGORIES

The operation and maintenance problems that are attributed to the maintenance manager’s lack of involvement during design development and review stages were classified under five categories, namely architectural, structural, electrical, mechanical, and HVAC design problems.

A summary of the assessed operation and maintenance problems categories’ average importance index values and rank of importance is illustrated in Table 5-12.

Table 5-12: Assessment operation and maintenance problems categories' average importance indexes and rank of importance

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during design development and review stages		Average Importance Index (%)	Rate of Importance	Rank
1.	**Architectural design problems**	**65.10**	**V.I**	**5**
2.	**Structural design problems**	**67.19**	**V.I**	**4**
3.	**Electrical design problems**	**74.20**	**V.I**	**3**
4.	**Mechanical design problems**	**77.82**	**V.I**	**1**
5.	**HVAC design problems**	**76.56**	**V.I**	**2**

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.7 RANKS OF THE SET OF CONCERNS AND/OR DETAILS CATEGORIES

The major Concerns and/or details raised by the maintenance manager during the design development and review stages at different project design phases (i.e. 30%, 60%, and 90%) were classified under five categories, namely architectural, structural, electrical, mechanical, and HVAC major concerns and/or details.

A summary of the assessed concerns' and or details' average importance index values and rank of importance (at 30% of project design) is illustrated in Table 5-13.

A summary of the assessed concerns' and or details' average importance index values and rank of importance (at 60% of project design) is illustrated in Table 5-14.

A summary of the assessed concerns' and or details' average importance index values and rank of importance (at 90% of project design) is illustrated in Table 5-15.

Table 5-13: Assessed set of concerns' and/or details' average importance indexes and rank of importance (at 30% of project design)

Major Concerns and/or details raised by the maintenance manager during design development and review stages (30% of project design)		Average Importance Index (%)	Rate of Importance	Rank
1.	Architectural major concerns and/or details	66.96	V.I	3
2.	Structural major concerns and/or details	81.25	V.I	1
3.	HVAC major concerns and/or details	79.17	V.I	2

Table 5-14: Assessed set of concerns' and/or details' average importance indexes and rank of importance (at 60% of project design)

Major Concerns and/or details raised by the maintenance manager during design development and review stages (60% of project design)		Average Importance Index (%)	Rate of Importance	Rank
1.	Architectural major concerns and/or details	70.83	V.I	5
2.	Structural major concerns and/or details	73.96	V.I	4
3.	Electrical major concerns and/or details	75.52	V.I	3
4.	Mechanical major concerns and/or details	78.91	V.I	2
5.	HVAC major concerns and/or details	88.02	E.I	1

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

Table 5-15: Assessed set of concerns' and/or details' average importance indexes and rank of importance (at 90% of project design)

Major Concerns and/or details raised by the maintenance manager during design development and review stages (90% of project design)		Average Importance Index (%)	Rate of Importance	Rank
1.	Architectural major concerns and/or details	70.63	V.I	5
2.	Structural major concerns and/or details	80.00	V.I	3
3.	Electrical major concerns and/or details	85.42	V.I	1
4.	Mechanical major concerns and/or details	74.70	V.I	4
5.	HVAC major concerns and/or details	80.65	E.I	2

E.I.: Extremely Important, V.I.: Very Important, I.: Important, SWI: Somewhat important, N.I: Not Important

5.8 DISCUSSION OF RESULTS

This section presents discussion of the results pertaining to operation and maintenance problems and set of concerns and/or details. Respondents to the questionnaire survey added no other significant or relevant operation and maintenance problems or concerns and/or details.

5.8.1 Operation and Maintenance Problems

The operation and maintenance problems were identified and classified under five categories, as detailed in chapter three. Each category included several problems. As presented in this chapter, the importance index and the rank for each problem under these categories were identified. The importance index of 0–<12.5% is categorized as ''Not Important''; 12.5–<37.5% is categorized as ''Somewhat Important''; 37.5–<62.5% is categorized as ‘‘Important’’; 62.5–<87.5% is categorized as ‘‘Very Important’’; and 87.5–100% is categorized as ‘‘Extremely Important’’, as illustrated in Table 5-1.

It is worth to say that the operation and maintenance problems that was mentioned and ranked depending on importance index might be important in the hot and humid region like Saudi Arabia. But in cold region, these problems might be one of the design requirements, like design and placement of large windows in building elevations facing the solar path.

It is believed that the operation and maintenance problems are identified depending on its important rather than the frequent of occurring, this due to the fact that the importance of the O & M problems means the maintenance cost, maintenance downtime and the safety of the occupants, while the frequent occurring of these problems depend on the number of occurrences and the cost of the maintenance.

5.8.1.1 Architectural

The group of operation and maintenance problems that are attributed to the architectural design received an average importance index of 65.1% (V.I) and was ranked as the fifth group in importance, as illustrated in Table 5-12 . This group included sixteen operation and maintenance problems. The two problems “Inability to maintain vertical risers due to the limited areas of the service shafts” and “Signs of stains and seepage due to improper rainwater drainage around windows” received the highest importance index values of 91.67% (E.I) and 79.17% (V.I), respectively as illustrated in Table 5-2. These results are viewed to be acceptable. This is due to the fact that both problems have negative effects on building systems maintainability and accessibility problem in operation and maintenance phase. Also the second problem affects the aesthetics of the building façades.

5.8.1.2 Structural

The group of operation and maintenance problems that are attributed to the structural design problems received an average importance index of 67.19% (V.I) and was ranked as the fourth group in importance as illustrated in Table 5-12. This group included eight operation and maintenance problems. The two problems “Plaster crack between concrete brick joints and wall-floor joints and “Damage to underground pipelines due to the settlement of soil and foundations” received the highest importance index values of 77.08% (V.I) and 72.92% (V.I), respectively as illustrated in Table 5-4. These results are viewed to be acceptable due to the fact that, the first problem affects the overall view of the interior finishes, and both of these problems need periodic expensive maintenance and repair.

5.8.1.3 Electrical

The group of operation and maintenance problems that attributed to the electrical design problems received an average importance index of 74.2% (V.I) and was ranked as the third group in importance as illustrated in Table 5-12. This group included thirteen operation and maintenance problems. The two problems “Exposed cabling and loose connections” and “Exposed plugs at open and wet areas” received the highest importance index values of 89.58% (E.I) and 85.42% (V.I), respectively as illustrated in Table 5-6. These results are viewed to be acceptable due to the fact that the first problem leads to fire ignition in building, thus threats to life and property loss. Also the exposed plugs at open areas lead to short circuits and periodic change of wires and cables.

5.8.1.4 Mechanical

The group of operation and maintenance problems that attributed to the mechanical design problems received an average importance index of 77.82% (V.I) and was ranked as the first group in importance as illustrated in Table 5-12. This group included seventeen problems. The two problems “Absence of detection and notification systems at hazardous areas” and “Absence of appropriate fire suppression systems” received the highest importance index values of 97.92% (E.I) and 89.58% (E.I), respectively as illustrated in Table 5-8. These results are viewed to be acceptable due to the fact that the first problem leads to fire ignition in building, thus threats to life and property loss.

5.8.1.5 HVAC

The group of operation and maintenance problems that attributed to the HVAC design problems received an average importance index of 76.56% (V.I) and was ranked as the second group in importance as illustrated in Table 5-12. This group included twelve problems. The two problems “Inadequacy of the HVAC system to provide the required comfort zone temperature” and “Poor indoor air quality that may cause infectious diseases and respiratory illnesses due to insufficient provision of fresh air” received the highest importance index values of 87.5% (E.I) and 85.42% (V.I), respectively as illustrated in Table 5-10. These results are viewed to be acceptable due to the significance of thermal comfort on the occupants in hot arid or humid climate.

As illustrated in Table 5-12, both “Mechanical design problems” and “HVAC design problem” received the highest average importance index values respectively.

5.8.2 Set of Concerns and/or Details

The set of concerns and/or details raised by the maintenance managers at different project design phases (i.e. 30%, 60% and 90%) were identified and classified under five categories. As presented in this chapter, the importance index and the rank for each problem under these categories were identified. The importance index of 0–<12.5% is categorized as ‘‘Not Important’’; 12.5–<37.5% is categorized as ‘‘Somewhat Important’’; 37.5–<62.5% is categorized as ‘‘Important’’; 62.5–<87.5% is categorized as ‘‘Very Important’’; and 87.5–100% is categorized as ‘‘Extremely Important’’, as illustrated in Table 5-1.

It is mandatory to ensure that the designer has been taken into account the modification required in one design stage before going to the next stage (i.e. moving from 30% to 60% of project design).

5.8.2.1 Set of Concerns and/or Details at 30% of project design

This section includes set of concerns and/or details at 30% of project design for three major disciplines, namely architectural, structural and HVAC.

5.8.2.1.1 Architectural at 30% of Project Design

The group of the architectural major concerns and/or details raised by the maintenance managers at 30% of project design received an average importance index of 66.96% (V.I), and was ranked as the third group in importance among the three major disciplines, namely architectural, structural and HVAC, as illustrated in Table 5-13. This group included seven major concerns and/or details. The two concerns and/or details “Check that the design considers access for the handicapped in terms of provision of suitable parking, emergency egress routes, toilets, ramps for circulation, and suitable elevator panels” and “Check that the design takes into account the ability to accommodate future changes in the layout as demanded by clients”, received the highest importance index values of 95.83% (E.I) and 79.17% (V.I), respectively as illustrated in Table 5-3. It is viewed that these concerns are highly significant due to the fact that the architects concentrate mainly on aesthetic of the buildings rather than the future changes in layout and handicap’s circulation requirements.

5.8.2.1.2 Structural at 30% of Project Design

The only major structural concern and/or detail raised by the maintenance manages at 30% of project design was “Check that the design provides for expansion joints when the length of the building exceeds that length specified by the codes”. It received an importance index of 81.25% (V.I), as illustrated in Table 5-13. It is viewed that this concern is highly significant in hot regions due to temperature fluctuation. Provision of expansion joints reduces future expansion and contraction problems that lead to cracks in tiles, slabs and façades, thus prevention of air leakage.

5.8.2.1.3 HVAC at 30% of Project Design

The group of the HVAC major concerns and/or details raised by the maintenance managers at 30% of project design received an average importance index of 79.17% (V.I) and was ranked as the second group in importance among the three major disciplines, namely architectural, structural and HVAC, as illustrated in Table 5-13. This group included three major concerns and/or details. The two concerns and/or details “Check that the cooling towers are located away from the adjacent buildings to eliminate background noise and emissions of mist” and “Check that the design provides access for reaching cooling towers, chillers, and condensers for maintenance” received the highest importance index values of 81.25% (V.I) and 79.17% (V.I), respectively as illustrated in Table 5-11. It is viewed that these concerns are highly significant in the design of the HVAC system to avoid both occupants’ interruption and building exposure to mist which leads to an increase in the dampness of façade finishes. In addition, provision of access to maintain the HVAC system components is also highly significant.

As illustrated in Table 5-13, the structural major concerns and/or details raised by the maintenance manages at 30% of project design received the highest average importance index value of 81.25% (V.I) and was ranked as the first group in importance.

5.8.2.2 Set of Concerns and/or Details at 60% of project design

This section includes set of concerns and/or details at 60% of project design for five major disciplines, namely architectural, structural, electrical, mechanical, and HVAC.

5.8.2.2.1 Architectural at 60% of Project Design

The group of the architectural major concerns and/or details raised by the maintenance managers at 60% of project design received an average importance index of 70.83% (V.I) and was ranked as the fifth group in importance (among the five groups) as illustrated in Table 5-14. This group included five major concerns and/or details. The two concerns and/or details “Check that the design provides access for fire fighting and egress routes” and “Check that basins of agriculture are located away from the facades to avoid dampness” received the highest importance index values of 95.83% (E.I) and 82.25% (V.I), respectively as illustrated in Table 5-3. It is viewed that these concerns are highly significant in the architectural design due to the facts that the fire fighting and egress routes are intended to save life and property. Locating agriculture basins away from the façade decreases dampness in the walls, hence, the development of cracks.

5.8.2.2.2 Structural at 60% of Project Design

The group of the structural major concerns and/or details raised by the maintenance managers at 60% of project design received an average importance index of 73.96% (V.I) and was ranked as the fourth group in importance as illustrated in Table 5-14. This group included only two major concerns and/or details. The two concerns and/or details “Check that the results of the soils bearing capacity tests are taken into consideration in the design of the foundation system” and “Check that the design provides for the required strength, thickness, and fire resistance rating of building construction materials” received the importance index values of 79.17% (V.I) and 68.75% (V.I), respectively as illustrated in Table 5-5. It is believed that these concerns are highly significant in the structural design due to the facts that taking the results of the soil bearing capacity tests eliminate the future settlements and its bad effects on building interior and exterior finishes as well as on the pipelines damage, and fire rating and resistance materials protect the occupants and provide them with the required time before building collapse.

5.8.2.2.3 Electrical at 60% of Project Design

The group of the electrical major concerns and/or details raised by the maintenance managers at 60% of project design received an average importance index of 75.52% (V.I) and was ranked as the third group in importance as illustrated in Table 5-14. This group included twelve major concerns and/or details. The two concerns and/or details “Check that the main board of circuit breakers is placed in a safe and visible location” and “Check that the design provides for grounding systems” received the highest importance index values of 87.5% (E.I) and 85.42% (V.I), respectively as illustrated in Table 5-7. It is believed that these concerns are highly significant in the electrical design due to the facts that visibility of main board of circuit breakers protects the building from any emergencies and possibility of fire ignition. Also, the provision of grounding systems protects the appliances from lightning effects.

5.8.2.2.4 Mechanical at 60% of Project Design

The group of the mechanical major concerns and/or details raised by the maintenance managers at 60% of project design received an average importance index of 78.91% (V.I) and was ranked as the second group in importance as illustrated in Table 5-14. This group included sixteen major concerns and/or details. The two concerns and/or details “Check that the design provides for shutoff valves for each hot and cold riser, as well as for all branches" and "Check that the design provides for appropriate systems for fire suppression, notification, and detection" received the highest importance index values of 95.83% (E.I) and 93.75% (E.I), respectively as illustrated in Table 5-9. It is believed that these concerns are highly significant in the mechanical design due to the facts that providing shut-off valves facilitate the maintenance process for the main and branch pipelines without total cut of water in the building, and inappropriate fire suppression and notification systems in the buildings expose the occupants to fire and put the building at property loss risk.

5.8.2.2.5 HVAC at 60% of Project Design

The group of the HVAC major concerns and/or details raised by the maintenance managers at 60% of project design received an average importance index of 88.02% (E.I) and was ranked as the first group in importance as illustrated in Table 5-14. This group included eight major concerns and/or details. The two concerns and/or details "Check that the design provides for air conditioning supply to toilets and ablution areas, these locations should be maintained at negative pressure with properly sized exhaust/extract fans" and "Check that there is no intermixing of the exhaust air from kitchens and toilets with the fresh air intake from fresh air handling units" received the highest importance index values of 95.83% (E.I) and 93.75% (E.I), respectively as illustrated in Table 5-11. It is believed that these concerns are highly significant in the HVAC design due to the facts that providing toilet with air conditioning supply and maintaining it at negative pressure eliminate the propagation of foul air to other spaces. Moreover, the return air from these spaces should not be mixed again with admitted air to the building.

As illustrated in Table 5-14, the group of the HVAC major concerns and/or details raised by the maintenance managers at 60% of project design received the highest average importance index between the five groups.

5.8.2.3 Set of Concerns and/or Details at 90% of project design

This section includes set of concerns and/or details at 90% of project design for five major disciplines, namely architectural, structural, electrical, mechanical, and HVAC.

5.8.2.3.1 Architectural at 90% of Project Design

The group of the architectural major concerns and/or details raised by the maintenance managers at 90% of project design received an average importance index of 70.63% (V.I) and was ranked as the fifth group in importance as illustrated in Table 5-15. This group included ten major concerns and/or details. The two concerns and/or details “Check that all the materials specified by the design professionals are available at the markets at that time” and “Check that the design documents and specifications provides for exterior doors that swing outward.” received the highest importance index values of 85.42% (V.I) and 79.17% (V.I), respectively as illustrated in Table 5-3. It is believed that these concerns are highly significant in the architectural design due to the facts that architects should be aware of the available materials in the local market. Moreover, specifying doors that swing outward facilitate the evacuation process in the case of fire ignition.

5.8.2.3.2 Structural at 90% of Project Design

The group of the structural major concerns and/or details raised by the maintenance managers at 90% of project design received an average importance index of 80.0% (V.I) and was ranked as the third group in importance as illustrated in Table 5-15. This group included five major concerns and/or details. The two concerns and/or details “Check that the specification provides for appropriate fireproofing and fire stopping materials in the building” and “Check that the specifications provide for adequate concrete cover for the steel reinforcement as specified by codes” received the highest importance index values of 91.67% (E.I) and 87.5% (E.I), respectively as illustrated in Table 5-5. It is believed that these concerns are highly significant in the structural design due to the facts that fireproofing and fire stopping provides for structural elements’ protection and saving it from collapse, also adequate concrete cover prevents concrete spalling and protect the steel reinforcement from corrosion.

5.8.2.3.3 Electrical at 90% of Project Design

The group of the electrical major concerns and/or details raised by the maintenance managers at 90% of project design received an average importance index of 85.42% (V.I) and was ranked as the first group in importance as illustrated in Table 5-15. This group included only two major concerns and/or details. The two concerns and/or details “Check that the specifications provides for the right diameter of cabling for the lighting system as well as for power plugs" and "Check that the specifications provide fluorescent ballasts that are electronic, high frequency, and of rapid start with no sound" received the importance index values of 93.75% (E.I) and 77.08% (V.I), respectively as illustrated in Table 5-7. It is believed that these concerns are highly significant in the electrical design due to the facts that the right diameter for cabling prevents any short circuit problems or need for replacement due to overload occurrence, and providing the fluorescent ballast provide for electrical saving and starting without flickering or any background noise.

5.8.2.3.4 Mechanical at 90% of Project Design

The group of the mechanical major concerns and/or details raised by the maintenance managers at 90% of project design received and average importance index of 74.70% (V.I) and was ranked as the fourth group in importance as illustrated in Table 5-15. This group included seven major concerns and/or details. The two concerns and/or details "Check that the specifications provide for the sealant type that will be used in filling the expansion joints" and "Avoid the specification of any unreinforced PVC at any exposed envelopes to solar radiation" received the highest importance index values of 83.33% (V.I) and 81.25% (V.I), respectively as illustrated in Table 5-9. It is believed that these concerns are highly significant in the mechanical design due to the facts that providing the right type of sealants prevents any future leakage, thus protecting the interior finishes, and not using the unreinforced PVC eliminates the exposed pipelines from future deformations due to the high temperature in Saudi Arabia.

5.8.2.3.5 HVAC at 90% of Project Design

The group of the HVAC major concerns and/or details raised by the maintenance managers at 90% of project design received an average importance index of 80.65% (V.I) and was ranked as the second group in importance as illustrated in Table 5-15. This group included seven major concerns and/or details. The two concerns and/or details “Check that the design provides a complete set of drawings and details of the fire/smoke system interlocking with the HVAC system” and “Check that the design provides a complete set of drawings and details for the air handling units, fan coil units, exhaust fans, fire/smoke system and the cooling tower plant” received the highest importance index values of 93.75% (E.I) and 91.67% (E.I), respectively as illustrated in Table 5-11. It is believed that both concerns are highly significant in the HVAC design due to the facts that providing the right set of drawing provides for ease of access and maintenance principle and facilitate any future needs for repair.

As illustrated in Table 5-15, the group of the electrical major concerns and/or details raised by the maintenance managers at 90% of project design received the highest average importance index between the five groups.

CHAPTER 6

INVESTIGATION OF THE CURRENT PRACTICES OF THE MAINTENANCE MANAGER'S INVOLVEMENT

6.1 BACKGROUND

Identification of the maintenance manager practices during the design development and review stages is critical for the effective understanding of the timing, procedure as well as the extent of the maintenance manager's involvement. Thus, the third objective of this study is to investigate the current practices of the maintenance manager's involvement during the design development and review stages in Saudi Arabia.

This objective has been achieved through part II of the questionnaire survey (appendix-A) .A questionnaire survey was formulated based on review of the literature and observed professional practices through face-to-face interviews with the engineering staff of the maintenance departments of two universities, namely King Fahd University of Petroleum and Minerals and Dammam University at the Eastern Province of Saudi Arabia.
The questionnaire survey was administered to the maintenance divisions' managers of 13 public Saudi Arabian universities. Twelve responses were obtained. The analysis of the questionnaire survey and the conducted interviews are discussed in this chapter.

6.2 DATA ANALYSIS FOR THE CURRENT PRACTICES OF MAINTENANCE MANAGERS

This section presents the analysis of the data received from the respondents (maintenance division's managers of **12** public Saudi Arabian universities) to part II of the questionnaire survey (appendix-A) which aimed at investigating the current practices of the maintenance manager's involvement during the design development and review stages.

6.2.1 Respondent's General Information

Section A of Part II of the questionnaire survey included four general questions about the respondent's name, contact information, his experience, number of years that the building stock has been in operation as well as if interested in receiving a summary of the finding of the study. Analysis of the data received was carried out using simple descriptive statistical techniques including graphics, percentages and summaries of the findings.

6.2.1.1 Respondent Experience in Maintenance Department

In this section, respondents were asked to specify their work experience in the maintenance department through selecting one out of four ranges of years of experience as follows: "Less than 5 years", "5 – 10 years", "10 – 20 years" and "Over 20 years". Figure 6.1 illustrates that that none of the respondent (0 out of 12) had less than 5 years experience, 41.67 % (5 respondents) had 5 – 10 years of experience, 16.67% (2 respondents) had 10 – 20 years of experience, 41.67% of the respondents (5 respondents) had more than 20 years of experience.

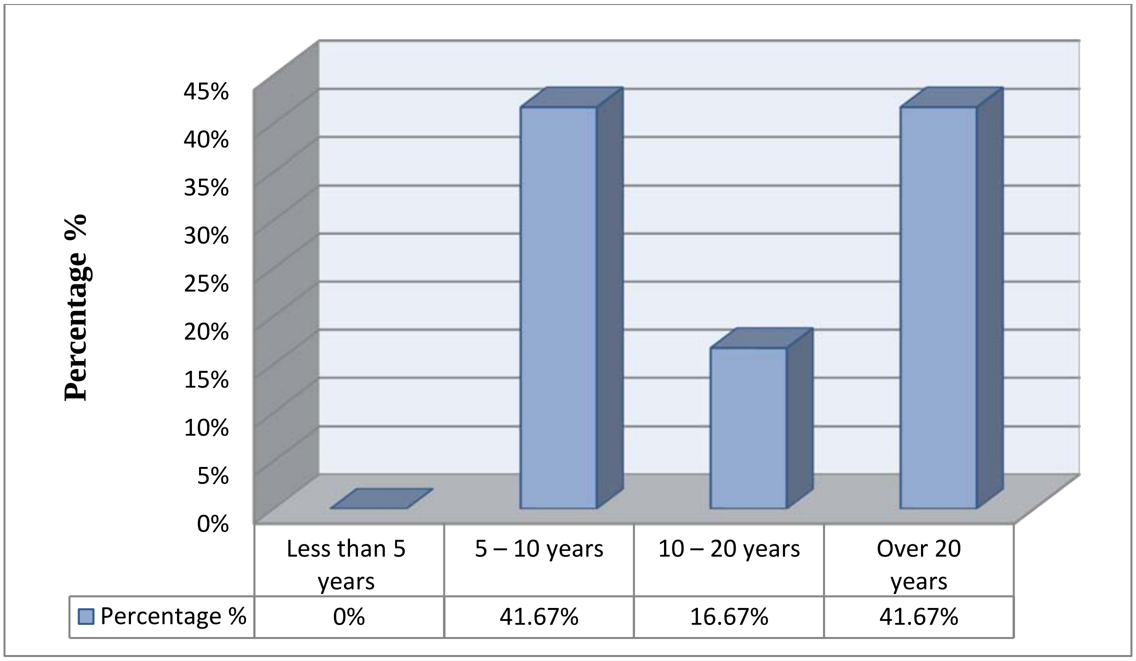

Figure 6.1: Respondents Years of Experience

6.2.1.2 Number of Year the Building Stock has been in Operation

In this section, respondents were asked to specify how long has the building stock in the campus been in operation through selecting one out of three options as follows: “Relatively new buildings (less than 10 years)”, “11 years old building and above” and “combination of the above”.

Figure 6.2 illustrates that only 16.67% of the universities (2 out of 12 universities) have relatively new buildings (less than 10 years old), no university has buildings that are only 11years old and above, 83.33% of the universities (10 out 12 universities) have a combination of relatively old and new buildings.

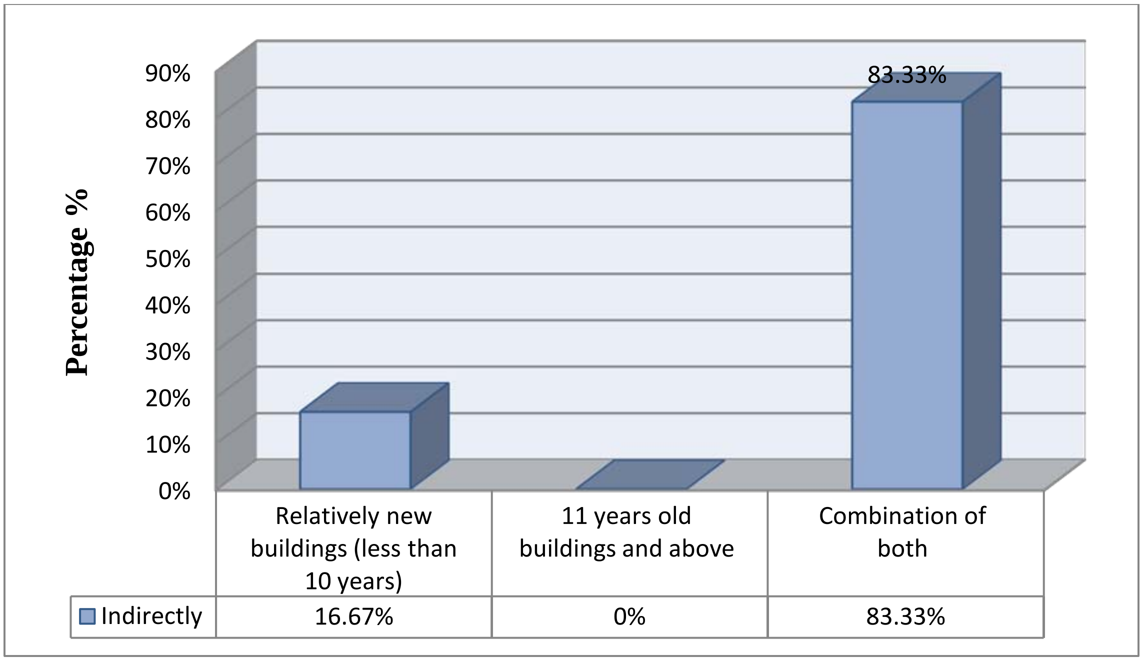

Figure 6.2: Number of Year the Building Stock has been in Operation

6.2.2 The current practices of maintenance managers' involvement

Section B of Part II of the questionnaire survey included ten questions pertaining to the current practices of the maintenance manager's involvement during the design development and review stages.

6.2.2.1 Occurrence of the maintenance managers' involvement

Questions#1 in section B of Part II aimed at investigating the occurrence of the maintenance manager's involvement or consultation with the design team. Figure 6.3 illustrates that 83% of the respondents (10 out of 12 respondents) have been involved or consulted during the design development and review stages in one way or another. Among those who have been involved, 17% have been involved quite often, 41% have been involved quite sometimes, and about 25% of them have rarely been involved. Only

17% (2 respondents) indicated that they have never been involved in the design development and review stages of any buildings.

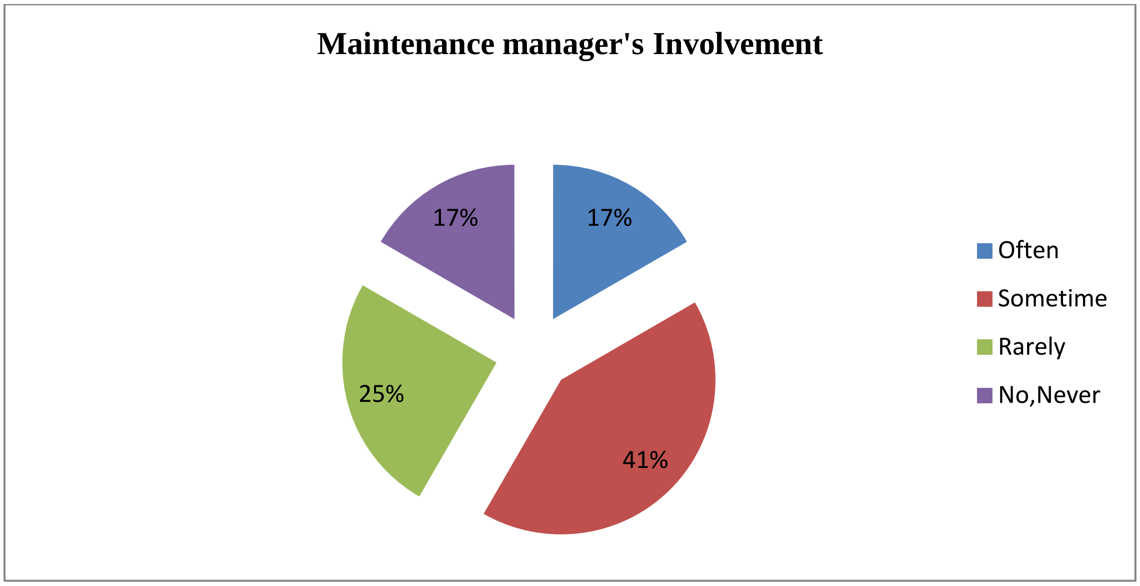

Figure 6.3: Occurrence of the maintenance managers' involvement

6.2.2.2 Approaches of the Maintenance Manager's involvement

Question # 2 in section B of Part II aimed at investigating the approaches followed for the method of involvement of the maintenance manager during the design development and review stages. Figure 6.4 illustrates that 20% of the respondents (2 out of 10 respondents) are involved directly with the integrated design team, while 80% of the respondents (8 respondents) are involved indirectly. None of the respondents have indicated any other approach for the involvement.

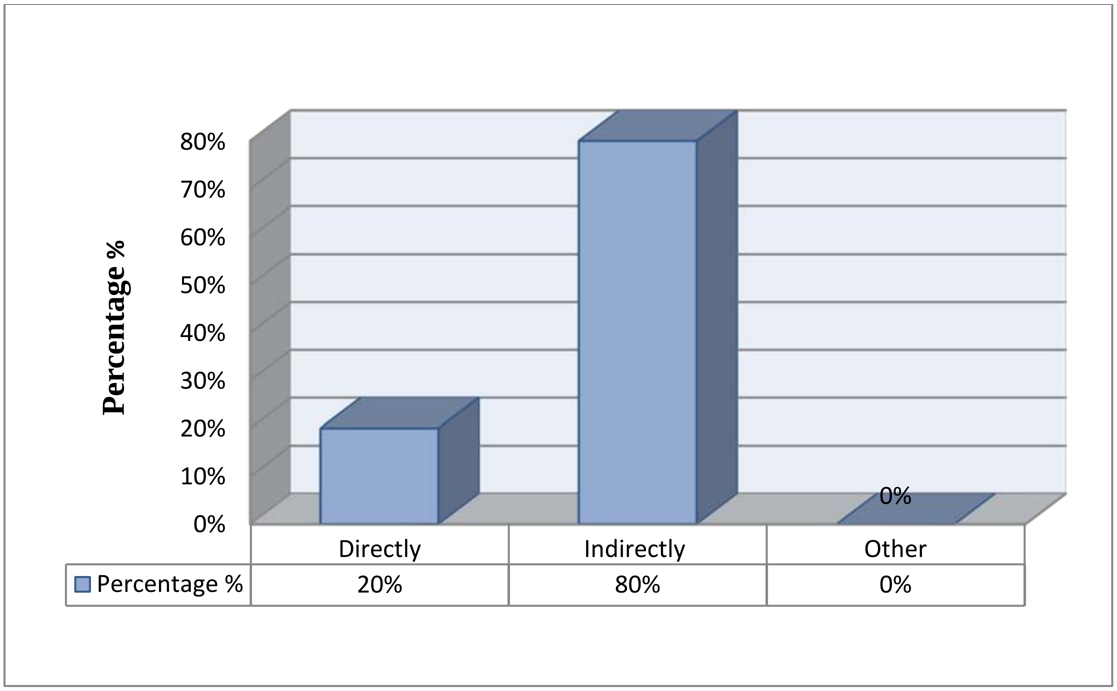

Figure 6.4: Approaches of the Maintenance Manager's involvement

Figure 6.5 illustrates that among the 8 respondents who have been involved indirectly, 12.5% of the respondents (1 out of 8 respondents) have been involved through a coordination office between the maintenance manager and the integrated design team, while 87.5% of the respondents (7 out of 8 respondents) have been involved indirectly through the project management department that acts as an interface between maintenance manager and the integrated design team

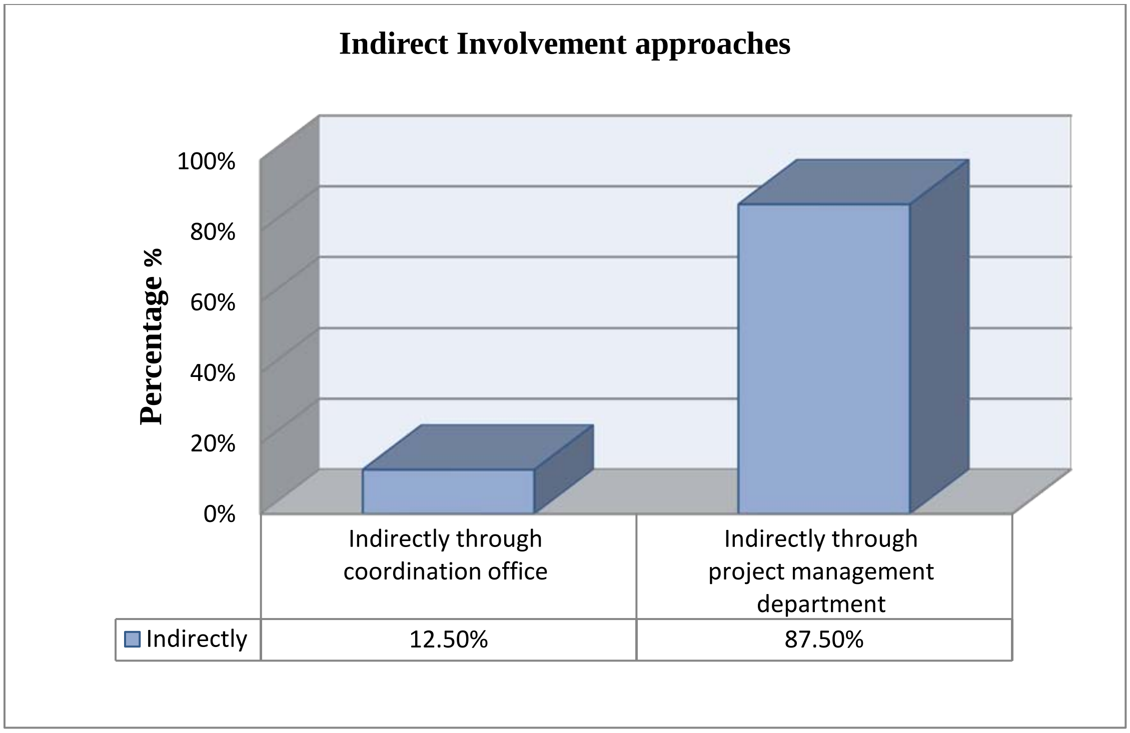

Figure 6.5: Indirect involvement approach

6.2.2.3 Way of Feedback from the Maintenance Manager

Question #3 in section B of Part II of questionnaire aimed at investigating the way of feedback from the maintenance manager (who is indirectly involved) to the integrated design team. Figure 6.6 illustrates that among 8 respondents who have been involved indirectly, 25% of respondent (2 out of 8 respondents) provide feedback through participation in design review meetings, 62.5% (5 respondents) provide feedback through commenting on a copy of the design documents sent for review, while 12.5% of the respondents (1 respondent) provide feedback through another method (i.e. providing their feedback after the completion of the design documents).

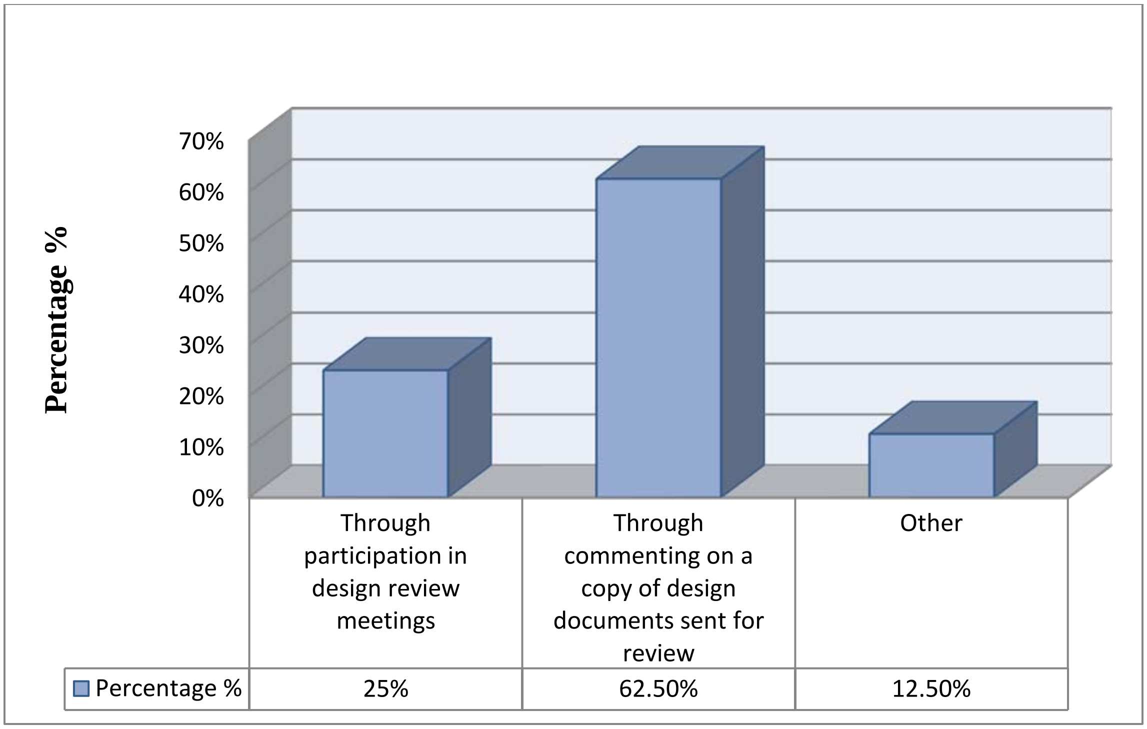

Figure 6.6: Way of Feedback process from the Maintenance Manager

6.2.2.4 The outcome of project reviews on the number of reported operation and maintenance problems

Question #4 in section B of Part II of questionnaire aimed at investigating whether the maintenance department still confronts the same problems after reviewing projects at the design stages and the outcome of project reviews on the number of reported operation and maintenance problems.

6.2.2.4.1 The architectural design problems

Figure 6.7 pertaining to architectural design problems illustrates that 10% of the respondents (1 out of 10 respondents) confirmed that their maintenance departments still confronts the same volume of operation and maintenance problems. 60 % of the respondents (6 respondents) confirmed that the volume of operation and maintenance problems has been decreased by “0 - 30%”, 10% of the respondents (1 respondent) confirmed that the volume of the problems has decreased by “30% - 60%”, while 20% of the respondents (2 respondents) confirmed that the volume of the problems has decreased by “60% - 90%”

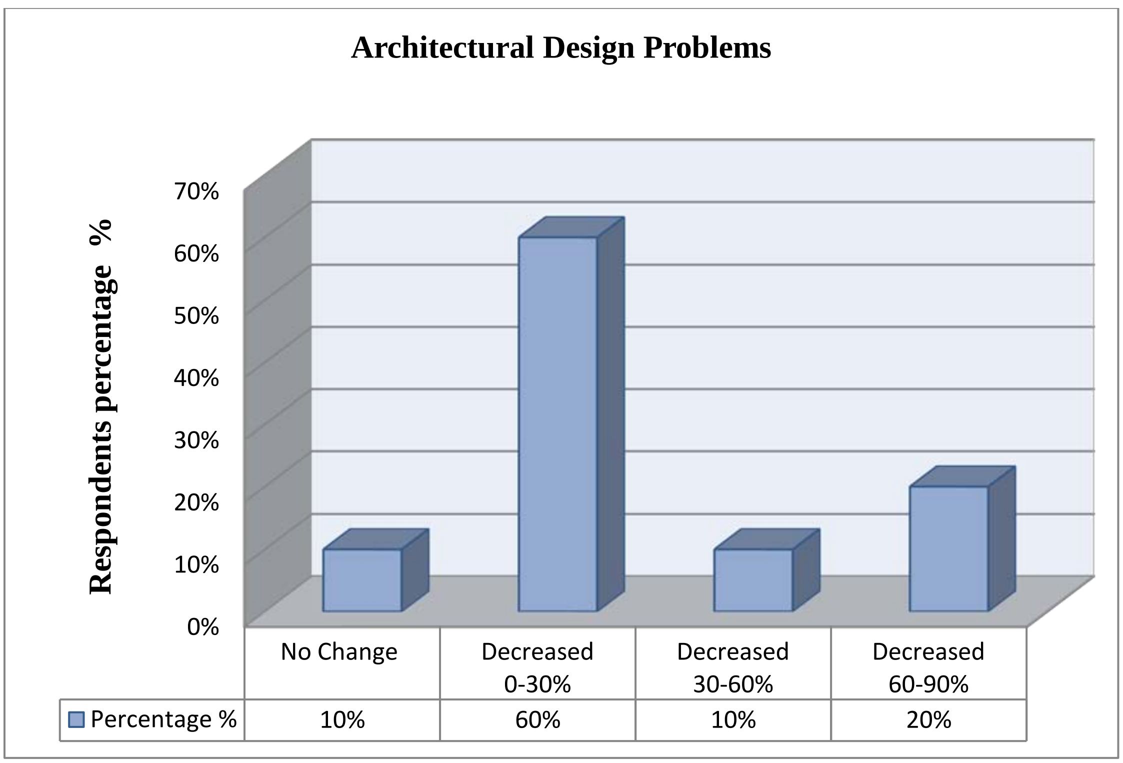

Figure 6.7: Number of reported architectural operation and maintenance problems

6.2.2.4.2 The structural design problems

As illustrated in Figure 6.8 which is related to structural design problems, 20% of the respondents (2 out of 10 respondents) confirmed that no change happened, 50 % of the respondent (5 respondents) confirmed the volume of structural design problems has decreased by “0 - 30%”, 10% of the respondents (1 respondent) confirmed that the volume of the problems has decreased by “30% - 60%”, while 20% of the respondents (2 respondents) confirmed that the volume of the problems has decreased by “60% - 90%”

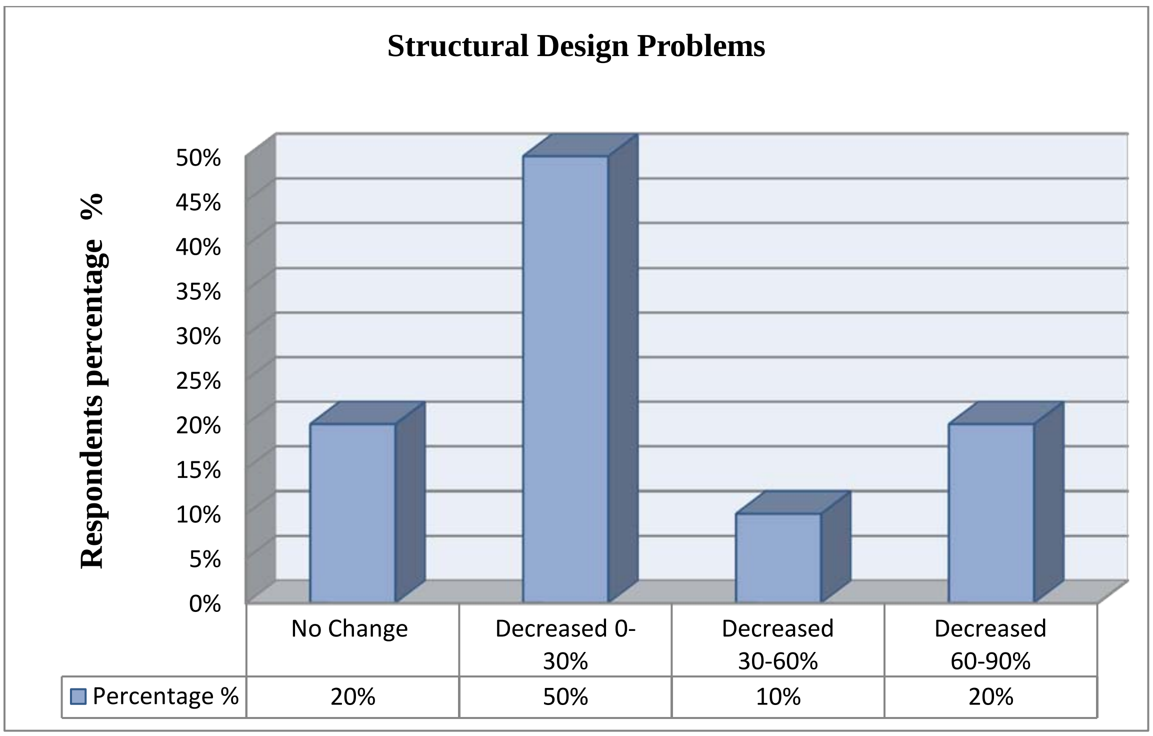

Figure 6.8: Number of reported structural operation and maintenance problems

6.2.2.4.3 The electrical design problems

As illustrated in Figure 6.9 which is related to electrical design problems, 10% of the respondents (1 out of 10 respondents) confirmed that no change happened, 10% of the respondents confirmed that the volume of the problems has decreased by “0% - 30%”, while 40 % of the respondent (4 respondents) confirmed the volume of electrical design problems has decreased by “30 - 60%”, also 40% of the respondents confirmed that the volume of the problems has decreased by “60% - 90%”,

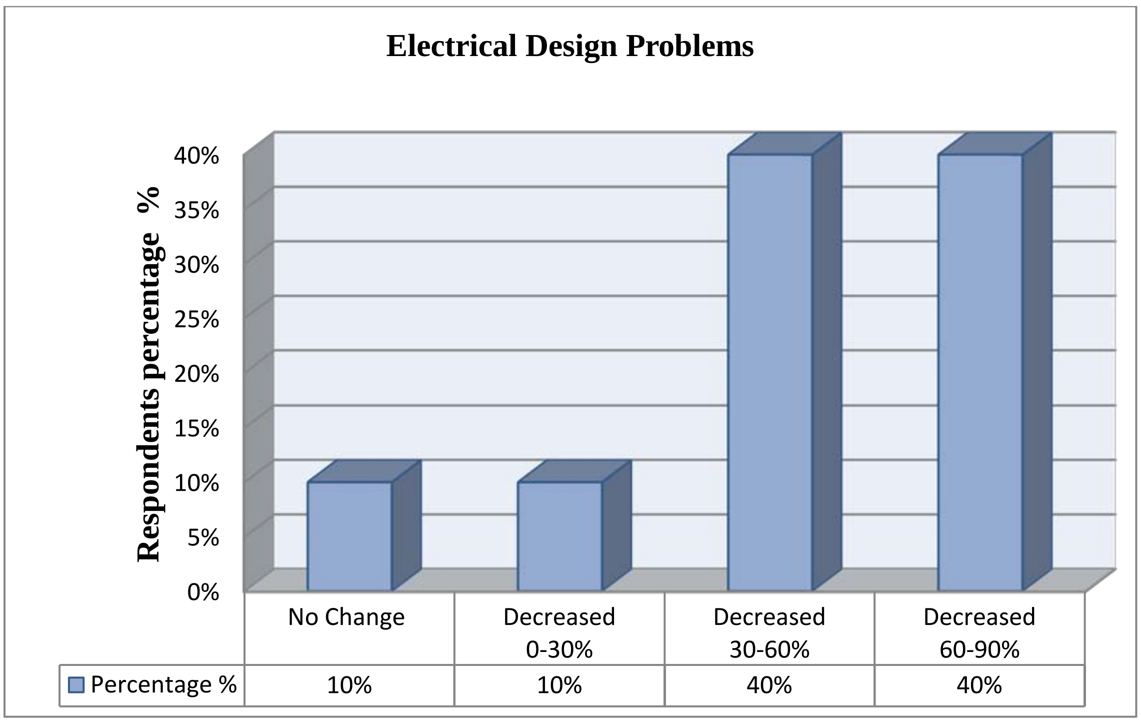

Figure 6.9: Number of reported electrical operation and maintenance problems

6.2.2.4.4 The mechanical design problems

As illustrated in Figure 6.10 which is related to mechanical design problems, 10% of the respondents (1 out of 10) confirmed that no change happened, 20% of the respondents (2 respondents) confirmed that the volume of the problems has decreased by “0% - 30%”, while 20% confirmed that the volume of the problems has decreased by “30% - 60%”, while 50% of the respondent (5 respondents) confirmed the volume of mechanical design problems has decreased by “60 - 90%”,

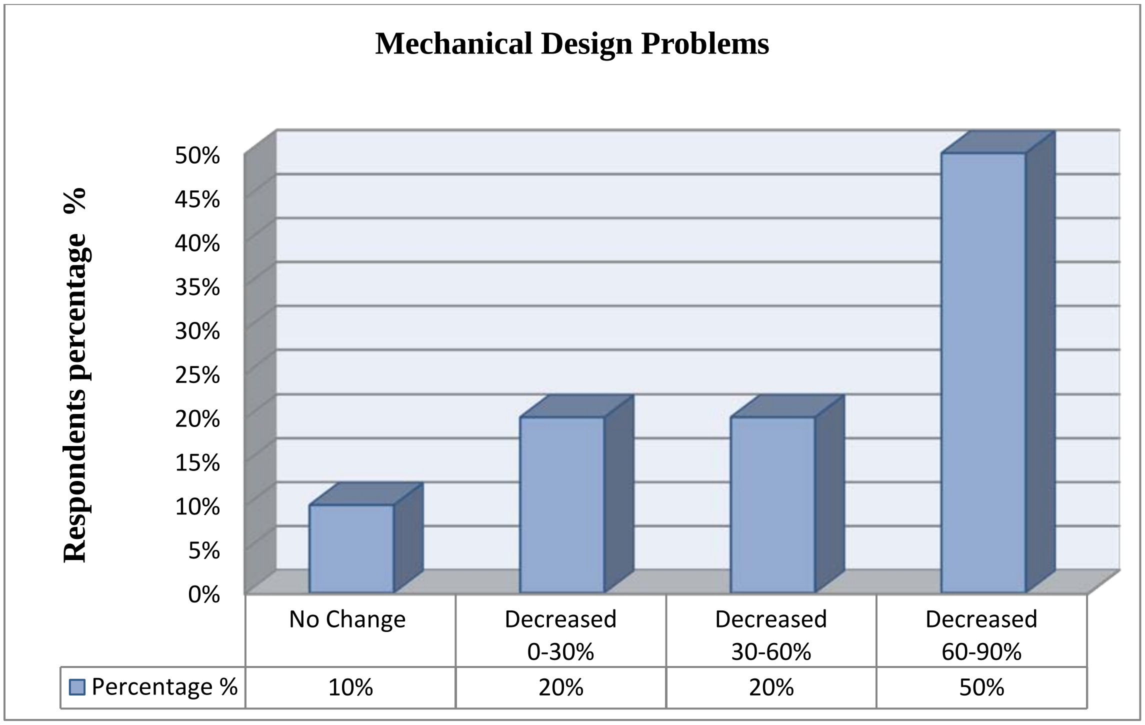

Figure 6.10: Number of reported mechanical operation and maintenance problems

6.2.2.4.5 The HVAC design problems

As illustrated in Figure 6.11which is related to HVAC design problems, 10% of the respondents (1 out of 10 respondent) confirmed that no change happened, 20% of the respondents (2 respondents) confirmed that the volume of the problems has decreased by “0% - 30%”, 10% confirmed that the volume of the problems has decreased by “30% -

60%”, while 60 % of the respondent (6 out of 10 respondents) confirmed the volume of HVAC design problems has decreased by “60 - 90%”,

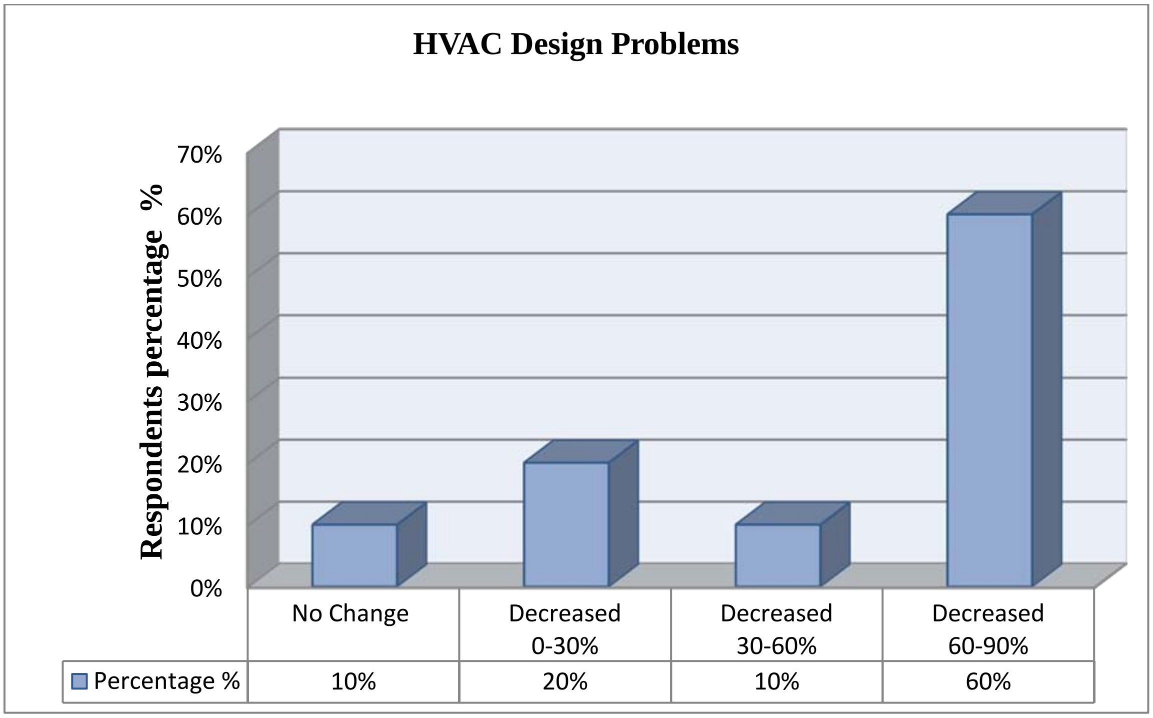

Figure 6.11: Number of reported HVAC operation and maintenance problems

6.2.2.5 Provision of feedback during the design process

Question #5 in section B of Part II of questionnaire aimed at investigating the stages of the design process during which the maintenance manager has been requested to provide feedback to the integrated design team. The respondents were asked to check all the answers that apply. Figure 6.12 illustrates that 2 out of 10 respondents (20% of the respondents) have been requested to provide feedback during the schematic design, 3 respondents (30% of the respondent) have been requested to provide feedback during the design development stage, 5 respondents (50% of the respondent) have been requested to provide feedback during the construction document stage, while 7 respondents (70% of the respondents) have been requested to provide feedback during the final documents stage.

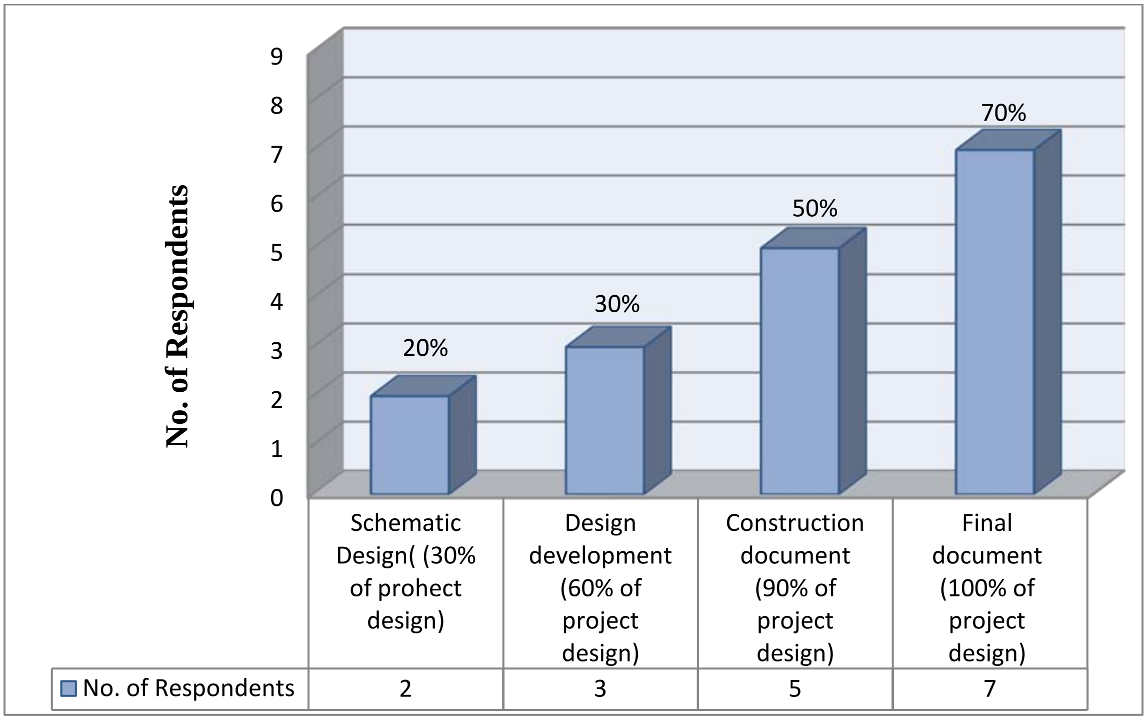

Figure 6.12: Stages of the design process during which the maintenance manager has been requested to provide feedback

6.2.2.6 Approaches for ensuring consideration of received feedback

Question #6 in section B of Part II of the questionnaire aimed at investigating the process of ensuring that the feedback of the maintenance manager has been taken into consideration. Figure 6.13 illustrates that 30% of the respondent (3 out of 10 respondents) ensure that their feedback has been taken into consideration through reviewing the re-submitted design documents, none of the respondents ensure that their feedback has been taken into consideration through reviewing the set of the design documents for the next stage, 60% of the respondents (6 respondents) ensure that their feedback has been taken into consideration through reviewing the final design documents at 100% completion, while 10% of the respondents (1 respondents) used another approach (i.e. does not ensure that his feedback is taken into consideration).

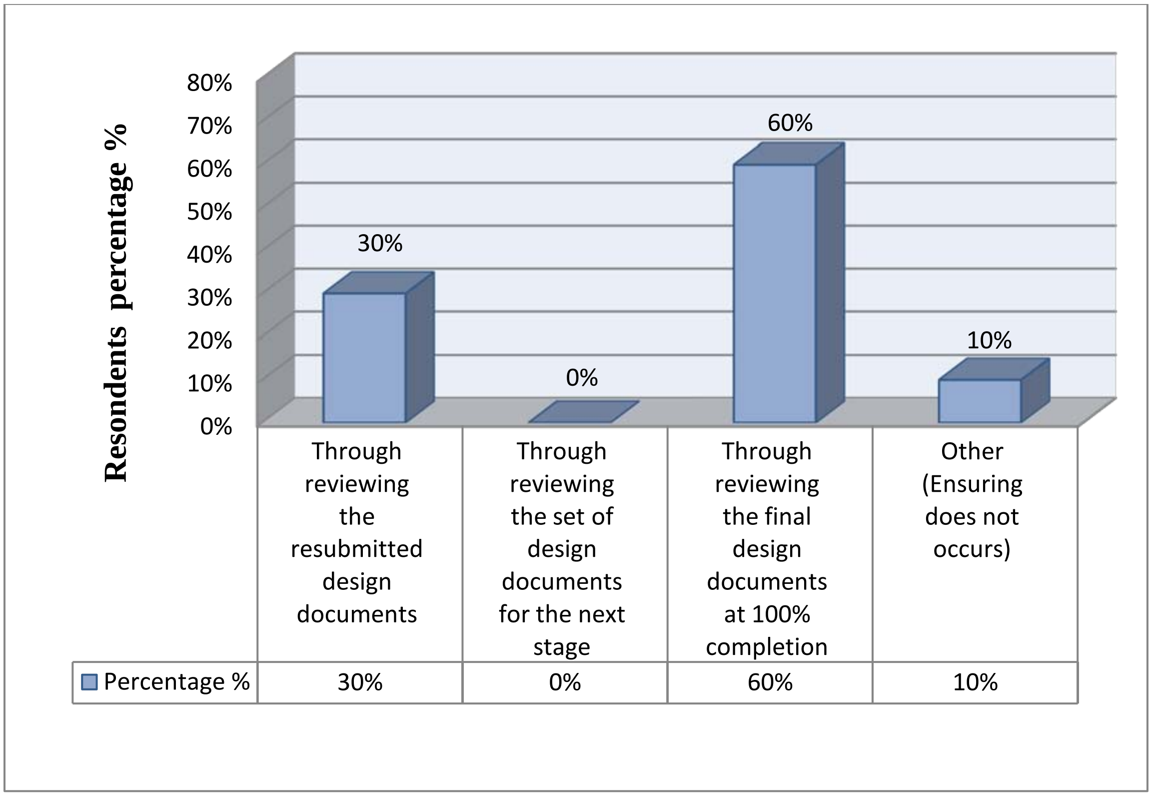

Figure 6.13: Approaches for ensuring consideration of received feedback

6.2.2.7 Documents on which the maintenance manager provide feedback

Question #7 in section B of Part II of the questionnaire aimed at investigating the documents on which the maintenance manager provides feedback to the integrated design team. Figure 6.14 illustrates that 20% of the respondents (2 out of 10 respondents) provide feedback on a complete set of drawings and specifications for all divisions of work, 60% of the respondents (6 respondents) provide feedback on drawings and specifications for particular divisions of work, 10% of the respondents (1 respondents) provides feedback on drawings only, and another 10% of the respondents provide on specifications only.

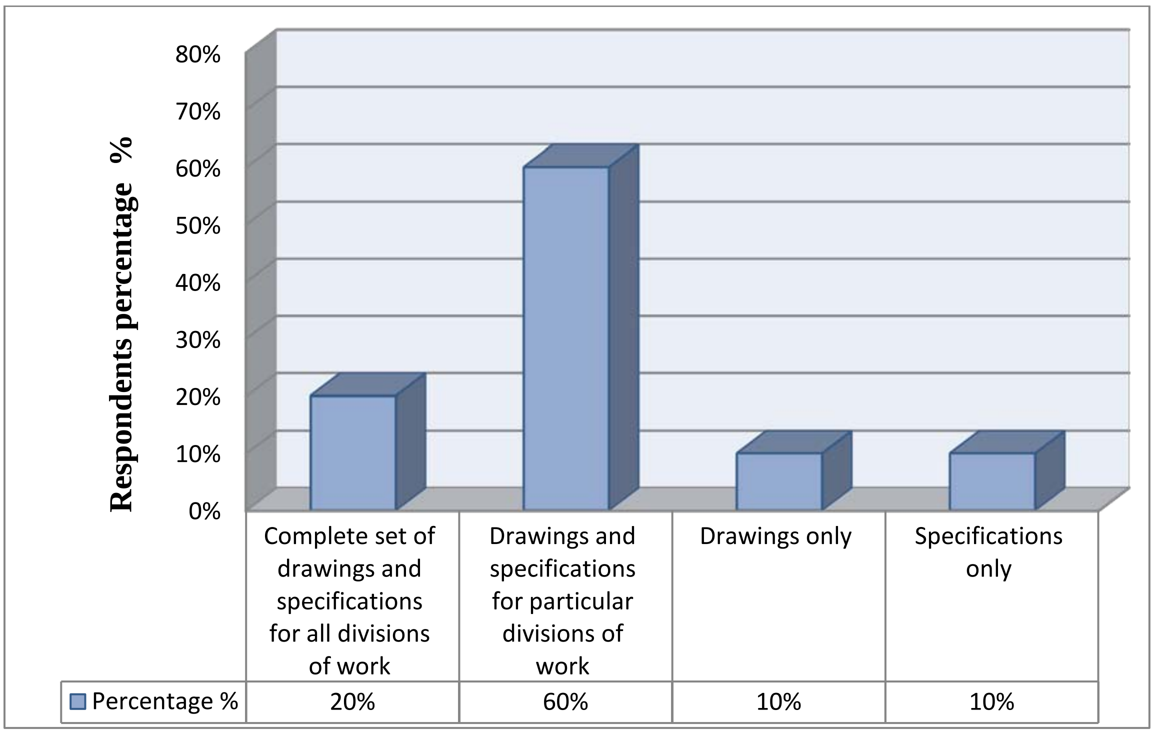

Figure 6.14: Documents on which the maintenance manager provide feedback

As presented in last figure, 60% of the respondents (6 out of 10 respondents) provide feedback on drawings and specifications for particular divisions of work, namely architectural, structural, electrical, mechanical, and HVAC. They were asked to check all answers that apply. Figure 6.15 illustrates that among the 6 respondents who provide feedback on drawings and specifications for particular divisions of work, 4 out of 6 respondents (67% of the respondents) provide feedback on the architectural division, 3 out of 6 of the respondents (50% of the respondents) provide feedback on the structural division, 5 out of 6 respondents (83% of the respondents) provide feedback on the electrical division, 5 out of 6 respondents (83% of the respondents) provide feedback on the mechanical division , while all the respondents (100% of the respondents) provide feedback on the HVAC division. Moreover, 1 respondent (17%) provides feedback on the drawings and specifications for another division of work (fire notification and protection systems).

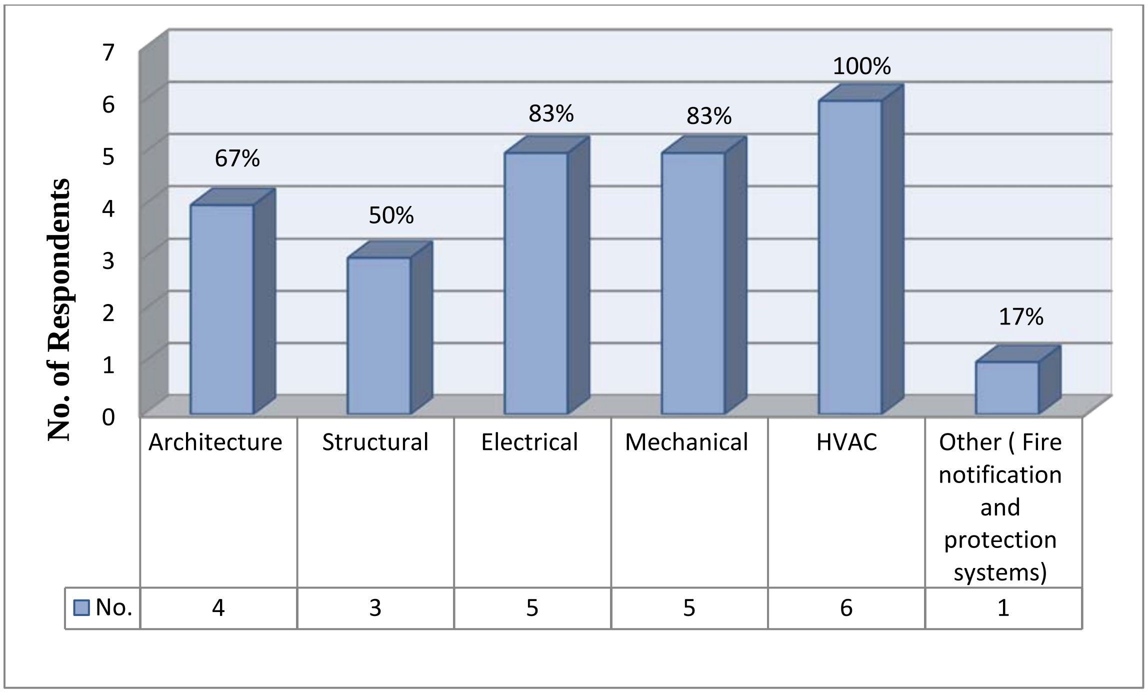

Figure 6.15: feedback on drawings and specifications for particular divisions of work

6.2.2.8 Categories of providing feedback by the maintenance manger

Question# 8 in section B of Part II of the questionnaire aimed at investigating the forms of providing feedback by that maintenance manager to the integrated design team. Respondents were asked to select all the methods that they carry out. Figure 6.16 illustrates that 9 out of 10 respondents (90% of the respondents) provide their feedback in the form of reviewing of the appropriateness of the systems type and performance data, 6 respondents provide their feedback in the form of reviewing specified materials and/or samples, 7 respondents provide their feedback in the form of reviewing the installation procedure through shop drawings, 5 respondents provide their feedback in the form of reviewing the specified equipment, 2 respondents provide their feedback in the form of reviewing the functional design alternatives, while 2 respondents provide their feedback in the form of reviewing the structural engineer's choice of the building structure.

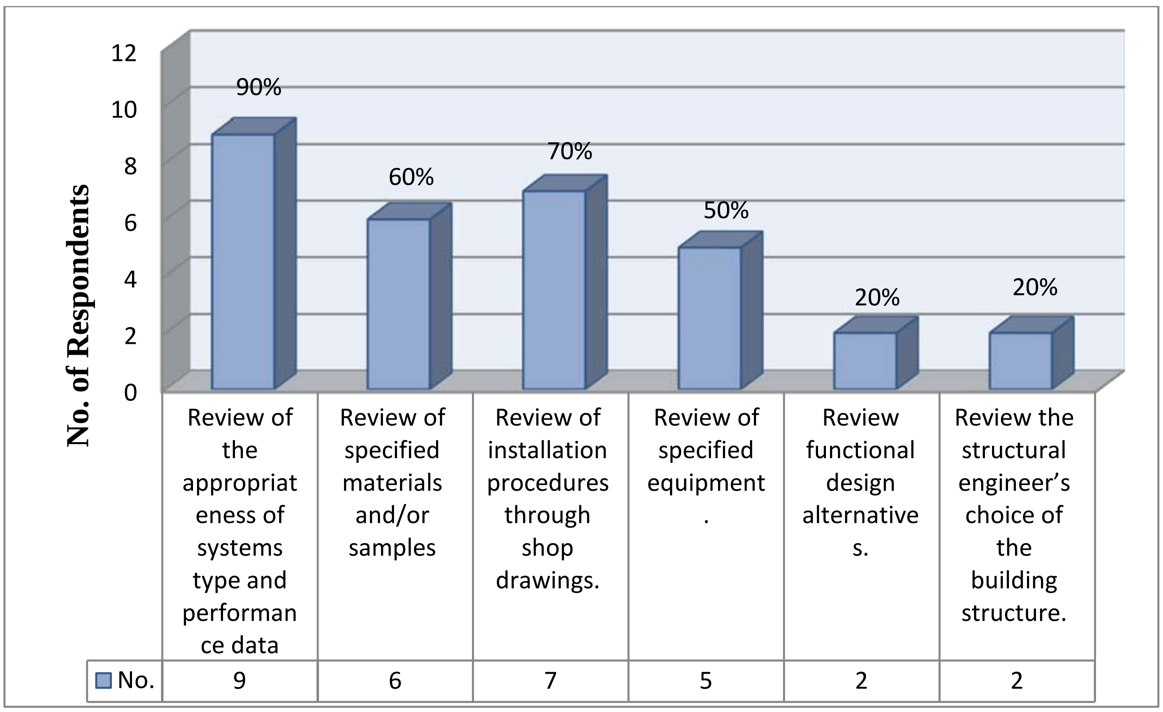

Figure 6.16: Forms of providing feedback by the maintenance manger

6.2.2.9 Credentials of the maintenance manager for providing feedback

Question # 9 in section B of Part II of the questionnaire aimed at investigating the bases on which the maintenance manager provides feedback to the integrated design team during the design development and review stages. Respondents were asked to select all the credentials for providing feedback. Figure 6.17 illustrates that all the respondents (100% of the respondents) provide feedback based on experience, 7 out of 10 respondents (70% of the respondents) provide feedback based on compliance with code requirements, and 5 respondents (50% of the respondents) provide feedback based on post occupancy evaluation experience.

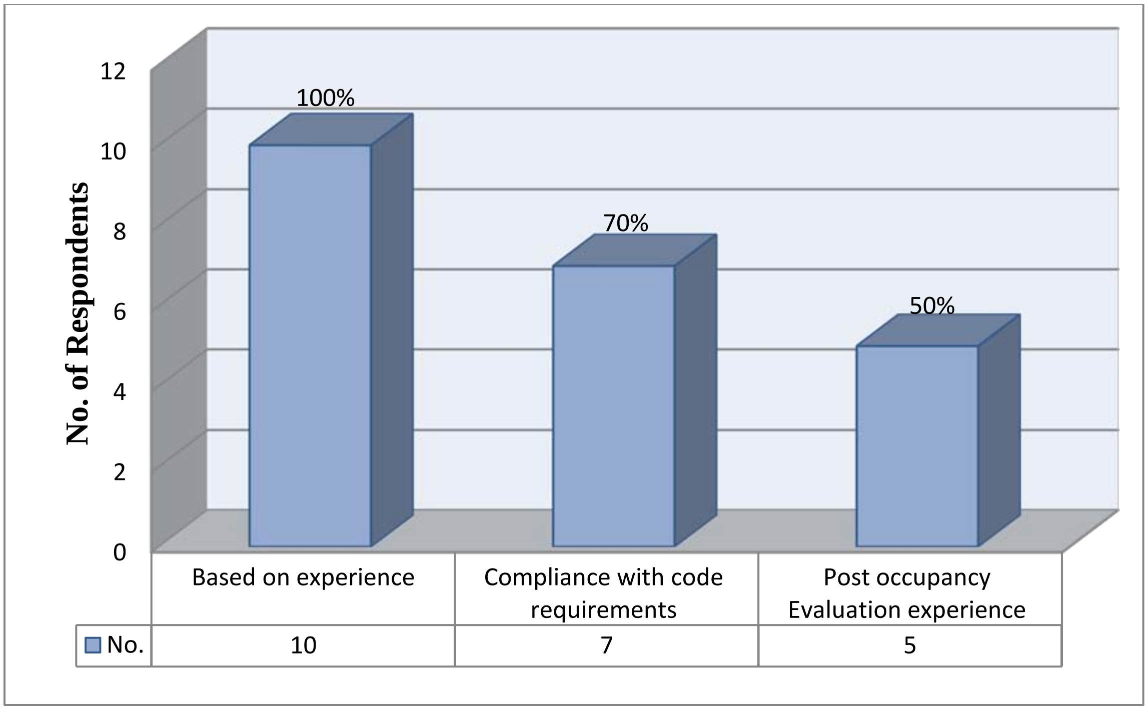

Figure 6.17: Bases on which the maintenance manager provides feedback

As presented in Figure 6.17, all the respondents (10 respondents) provide feedback based on their experience, the respondents were asked to be more specific and check all the answers that apply. Figure 6.18 illustrates that among the 10 respondents, 6 respondents (60% of the respondents) provide feedback based on experience in building components which are the most economical to repair and replace, 2 respondents provide feedback based on experience in building components which are the most difficult to inspect and have access to, while all the respondents (100% of the respondents) provide feedback based on experience acquired through receiving complaints from users.,

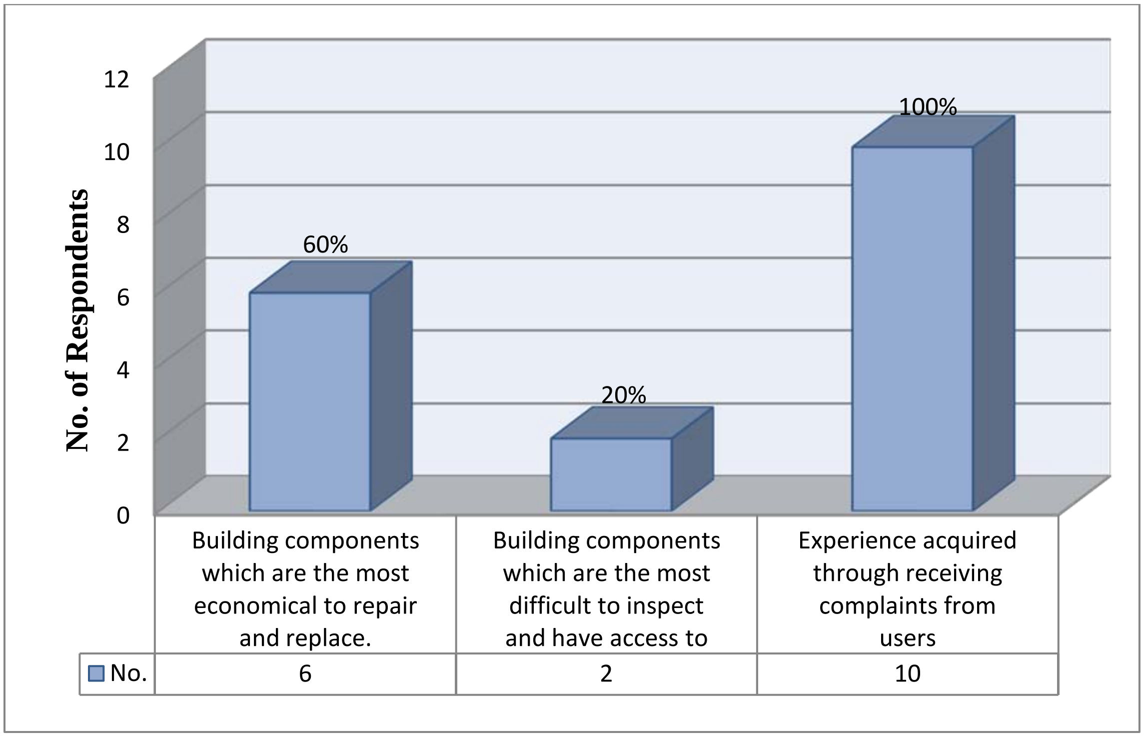

Figure 6.18: Feedback provided based on experience

As presented in Figure 6.17, 7 respondents out of 10 provide feedback based on compliance with international code requirements, those respondents were asked to select all the international codes that they use from the list. Figure 6.19 illustrates that among those 7 respondents, all of respondents (100% of respondents) provide feedback based on compliance with the requirements of the international fire code, 6 out of 7 respondents (83%) provide feedback based on compliance with the requirements of the international energy conservation code, 6 respondents (83%) provide feedback based on compliance with the requirements of the international plumping code, 5 respondents (71%) provide feedback based on compliance with the requirements of the international private sewage disposal code, 4 respondents (57%) provide feedback based on compliance with the requirements of the international mechanical code, 2 respondents (29%) provide feedback based on compliance with the requirements of the international property maintenance code, also 2 respondents(29%) provide feedback based on compliance with the requirements of the international green construction code and finally, 1 respondent (14%) provides feedback based on compliance with the requirements of international existing building code.

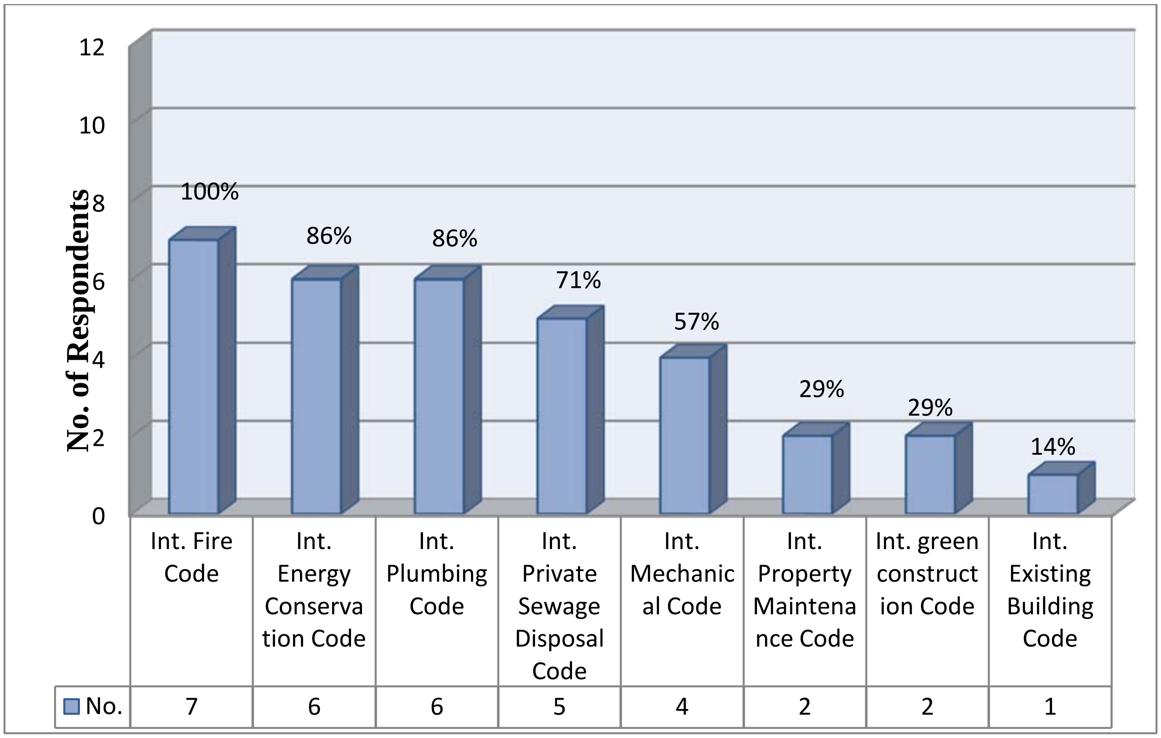

Figure 6.19: Feedback provided based on compliance with international code requirements

6.2.2.10 The most significant design stage review on future maintenance works

Question # 10 in section B of Part II of the questionnaire aimed at identifying the most significant design stage review that will result in a significant reduction in future maintenance works. Figure 6.20 illustrates that none of the respondents select either schematic design stage (30% of project design) or construction document stage (90%of project design), 90% of the respondents (9 out of 10) select design development stage (60% of project design), where 10% of the respondents (one respondent) select final document, construction administration stage (100% of project design).

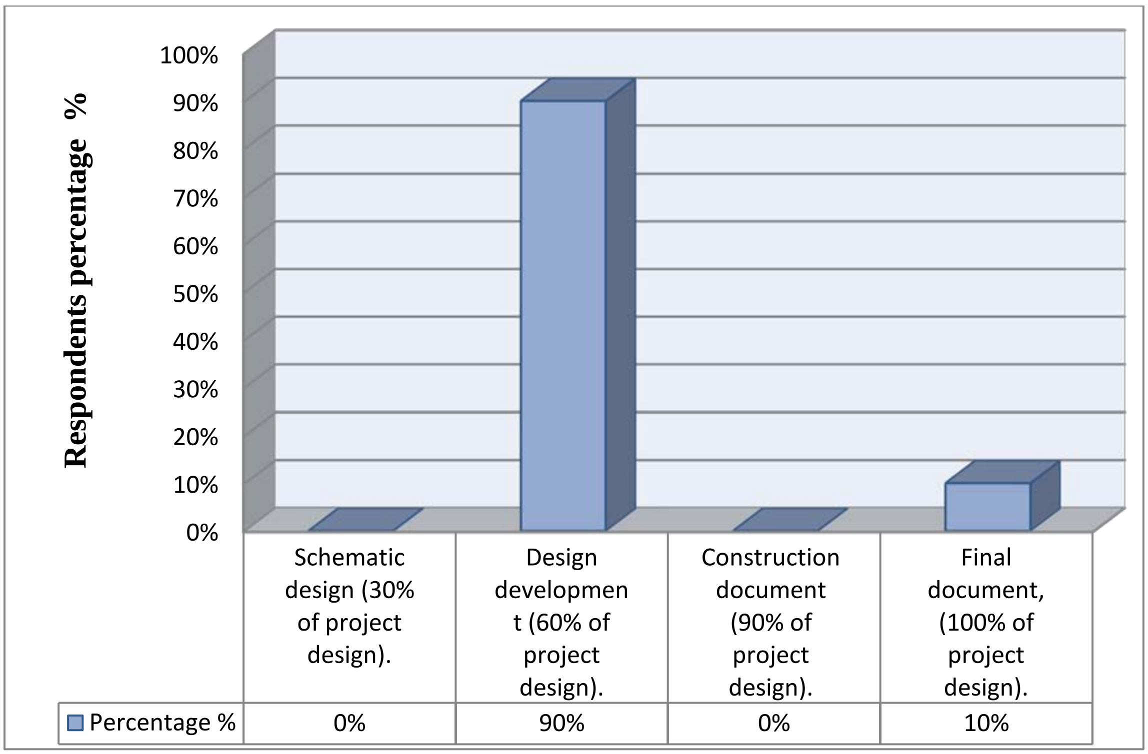

Figure 6.20: The most significant design stage review on future maintenance works

6.3 DISCUSSION

Lack of communication between the building design team and the maintenance manager is the main cause of design-related maintenance problems. Careful planning for maintainability during the design phase will provide for less operation and maintenance problems. As illustrated in Figure 6.3, 83% of the respondents (10 out of 12 respondents) to the questionnaire survey indicated that they have been involved or consulted during the design development and review stages in one way or another. This finding is similar to survey done by Arditi & Nawakorawit, (1999) on property managers. It showed that 85% of the respondents have been involved in one way or another and only 15% of the respondent said they have never been involved in buildings design process.

The maintenance manager's involvement occurs either directly or indirectly. In the direct involvement method, the maintenance manager would make a direct contact with the integrated design team. In the indirect involvement method, the approach followed for the involvement could be either through a coordination office between the maintenance manager and the integrated design team, or through the project management department that acts as an interface between maintenance manager and the integrated design team. As illustrated in Figure 6.4, 80% of the respondents (8 respondents) are involved indirectly with the integrated design team. Among the 8 respondents who have been involved indirectly, 87.5% of the respondents (7 out of 8 respondents) have been involved indirectly through the project management department that acts as an interface between maintenance manager and the integrated design team, as illustrated in Figure 6.5. It is believed that designers perceive maintenance managers to lack the necessary qualifications to review the design documents. Therefore, design professionals cannot accept the maintenance manager as an equal dialogue partner in the design stage review (Jaunzens et al, 2001).

The maintenance manager has been involved indirectly through either the coordination office or through the project management department. Feedback from the maintenance manager (who is indirectly involved) to the integrated design team can be provided through two ways. The first is through participation in the design review meetings with the coordination office or the project management department. The second way of feedback is through communicating on a copy of the design document sent for review for the coordination office or the project management department. As illustrated in Figure 6.6, 62.5% (5 respondents) provide feedback through commenting on a copy of the design documents sent for review.

The maintenance manger may be requested to provide feedback to the integrated design team in one or more stages of the design process. The first of these stages is the schematic design stage, in which 30% of project design is completed. It is defined as "the first phase in the design of a project where an architect/engineer prepares schematic diagrams giving a general view of the components and the scale of the project after detailed discussions with the client" (BusinessDictionary.com, 2012c). The second stage is the design development, in which 60% of project design is completed. It is defined as "a transitional phase of an architect/engineer (A/E) services in which the design moves from the schematic phase to the contract document phase. In this phase, the A/E prepares drawings and other presentation documents to crystallize the design concept and describe it in terms of architectural, electrical, mechanical, and structural systems. In addition, the A/E also prepares a statement of the probable project cost" (BusinessDictionary.com, 2012b). The third stage is the construction document stage, in which 90% of project design is completed. It is defined as "the third stage of services provided by architect and/or engineer in which he or she prepares working drawings, specifications, and bidding documents" (BusinessDictionary.com, 2012a). The fourth and final stage is the construction administration phase, where the design of the project reaches the level of 100% completion. As illustrated in Figure 6.12, 7 respondents (70% of the respondents) have been requested to provide feedback during the final documents stage (100% design completion). It is believed that this involvement with the integrated design team would be too late to provide practical feedback that can be incorporated in the design documents.

There exist three approaches for the maintenance manger to ensure that his feedback has been taken into consideration. These approaches include reviewing the re-submitted design documents, reviewing the set of the design documents for the next stage and reviewing the final design documents at 100% completion. As illustrated in Figure 6.13, 60% of the respondents (6 respondents) ensure that their feedback has been taken into consideration through reviewing the final design documents at 100% completion.

The maintenance manager could provide feedback to the integrated design team on four types of documents. These documents are a complete set of drawing and specifications for all divisions of work; drawings and specifications for particular divisions of work, namely architectural, structural, electrical, mechanical and HVAC; drawings only; and specifications only. As illustrated in Figure 6.14, 60% of the respondents (6 respondents) provide feedback on drawings and specifications for particular divisions of work. Among the 6 respondents who provide feedback on drawings and specifications for particular divisions of work, all the respondents (100%) provide feedback on the HVAC division, as illustrated in Figure 6.15.

There are six methods of providing feedback by the maintenance manager to the integrated design team to avoid the problems that are currently experienced in building operation and maintenance. These methods include review of the appropriateness of system types and performance data, the specified materials and/or samples, the installation procedures through shop drawings, the specified equipment, the functional design alternatives and the structural engineer's choice of the building structure. As illustrated Figure 6.16, 9 out of 10 respondents (90% of the respondents) provide their feedback in the form of reviewing of the appropriateness of the systems type and performance data.

The maintenance manager provides his feedback to the integrated design team during the design development and review stages based on three different types of qualifications. The first of these qualifications is his experience in the operation and maintenance field. This includes experience with (1) the most economical building components to repair and replace, (2) the most challenging building components to inspect and gain access to, and (3) the complaints received from users. The second type of qualifications is knowledge of the requirements of the different international codes that the building has to comply with. These codes include the fire code, energy conservation code, plumping private sewage disposal, mechanical code, property maintenance code, green construction code and existing building code. The third type of qualification is results of post occupancy evaluation. Figure 6.17 and Figure 6.18 illustrate that all the respondents (100%) provide feedback based on experience acquired through receiving complaints from users.

CHAPTER 7

A FRAMEWORK TO PRIORITIZE MAJOR CONCERN AT THE MOST SIGNIFICANT PROJECT DESIGN STAGE

7.1 BACKGROUND

As presented in chapter six, the most significant project design stage occurs at 60% completion of the project design. In chapter four, forty three major concerns and/ or details at the 60% completion of project design were identified and classified under five categories. Five concerns (5 out of 43) were classified under architectural major concerns and/or details category, two concerns were classified under structural major concerns and/or details category, twelve concerns were classified under electrical major concerns and/or details category, sixteen concerns were classified under mechanical major concerns and/or details category and eight concerns (8 out of 43) were classified under HVAC major concerns and/or details category. In chapter five of this study, these major concerns and/or details were assessed by selecting one of the following evaluation terms, “Extremely Important”, “Very Important”, “Important”, “Somewhat Important” and “Not Important”. Then, the importance indexes for the concerns and/or details were calculated. The assessment was carried out by the directors of maintenance department divisions (architectural, structural, electrical, mechanical, and HVAC). This assessment was conducted to identify the level of importance of each of these concerns and/or details and to see whether any more concerns could be included in the evaluation.

This chapter presents the development of a framework for prioritizing the major concerns and / or details raised by the maintenance manager during the design development stage (60% of project design). Development of the framework required the following activities:

1. Assigning alphabetical letters to the 43 major concerns, as illustrated in table 7.2.
2. Developing a scoring matrix including all alphabetical letters for the 43 major concerns, as illustrated in (Appendix-C).
3. Conducting a pair-wise comparison for each of the concerns. Each concern is compared with the rest of the concerns based on the inclination of an expert in the professional domain of building defects and maintenance.
4. Once the comparative evaluations for all of the 43 concerns are performed by each expert, the raw score of each concern is calculated by summing the assigned letters in the matrix. The average raw score for each concern was calculated based on the raw score of each expert's matrix, as illustrated in table 7.2.
5. The ranking of each concern was determined based on the value of its average raw score.

7.2 PAIRED COMPARISON OF CONCERNS AND/OR DETAILS

In this section, the important forty three concerns at design development stage (60% of project design) are identified in the criteria scoring matrix. The criteria scoring matrix was completed by three maintenance managers as subject matter experts. Two of the experts were from King Fahd University of Petroleum and Minerals, while the third was from Dammam University. Selection of the experts was based on their knowledge and professional experience in the domain of building operation and maintenance, in addition to their frequent involvement at the various stages of project design development and review stages.

The three experts were provided with a thorough explanation on the methodology of performing pair-wise comparison for the purpose of evaluating and ranking the forty three concerns. The importance of one concern over another can be “major” with 3 points, “medium” with 2 points, and “minor” with 1 point, as illustrated in Table 7-1 Moreover, when two concerns have equal importance, they can be indicated as equal by using both letters in scoring matrix.

Table 7-1: Importance of evaluation terms

Evaluation	**Important**
Major Importance	3
Medium Importance	2
Minor Importance	1
Two letter mean have equal priority	

Saaty (1994) indicates that pair-wise is a preferred method for comparing between two important entities at the same time. The method provides the decision maker with judgment on the preferred entity. As the pair-wise comparisons for the forty three major concerns were carried out by three experts in the criteria scoring matrix (appendix-C), the number of judgment required to develop or fill the scoring matrix is equal to $\frac{n\,(n-1)}{2}$

In our case, the total number of comparisons was equal to $\frac{43\ (43-1)}{2}$ = 903 comparisons in each expert's scoring matrix. After that, the row score of each concern is totaled by summing the assigned letters in the matrix. Table 7-2 illustrates the row score from three different experts' scoring matrix, average row score and the rank for each concern. The average row score was calculated by dividing the summation of total row score from three different experts' scoring matrix over three, which is the number of experts.

Table 7-2: The row score from three different experts' scoring matrix, average row score and the rank for each concern and/or details

Cat.	NO.	Set Of Concerns and/or Detail at 60% Of Project Design	Row Score (1)	Row Score (2)	Row Score (3)	Row Score (Average)	Rank
Architectural Concern	A	Check that the architectural form of the building provides for ease of cleaning and maintenance of the fenestration.	1	19	20	13.3	**39**
	B	Check that basins of agriculture are located away from the facades to avoid dampness	0	24	14	12.7	**41**
	C	Check that the design provides the kitchens and bathrooms with windows.	7	18	15	13.3	**40**
	D	Check the provision of enough areas for exhaust and service shafts of kitchens and bathroom	7	30	46	27.7	**32**
	E	Check that the design provides access for fire fighting and egress routes.	66	67	87	73.3	**5**
Structural Concern	F	Check that the results of the soils bearing capacity tests are taken into consideration in the design of the foundation system.	44	46	40	43.3	**19**
	G	Check that the design provides for the required strength, thickness, and fire resistance rating of building construction materials	16	44	37	32.3	**28**

Electrical Concerns	H	Check that the main board of circuit breakers is placed in a safe and visible location.	32	24	2	19.3	**37**
	I	Check that the design provides for a circuit breaker for each power plug in kitchens as well as for all room light switches.	14	20	34	22.7	**34**
	J	Check that the design provides for a sufficient number of luminaries to provide the required illumination intensity.	19	16	30	21.7	**35**
	K	Check that the design provides for lighting switches adjacent to access points.	25	16	54	31.7	**29**
	L	Check that the design provides for lighting in the elevator shaft.	11	6	6	7.7	**43**
	M	Check that the design provides for a sufficient number of power plugs to avoid the use of extension cords.	19	25	54	32.7	**27**
	N	Check that the design provides for a fan coil unit - with single point electrical connection box - for power supply and control.	26	5	6	12.3	**42**
	O	Check that the designer provides for clear cable management and identification	24	15	24	21	**36**
	P	Check that the designer provides for communication and internet lines to the all spaces in the building	19	15	49	27.7	**33**
	Q	Check that the design provides for backup power supply, emergency lighting, and address wiring of fire notification systems, and detection systems	37	40	33	36.7	**25**
	R	Check that the provided communication internet lines are away from power and lighting lines	15	15	27	19	**38**
	S	Check that the design provides for grounding systems.	92	38	53	61	**7**

Mechanical Concerns	T	Check that there are no pipelines penetrating the walls or the roof.	25	55	78	52.7	**11**
	U	Check that the design provides for a complete layout for all the pipelines.	28	25	59	37.3	**24**
	V	Check that all the supply pipelines are not running through the slabs.	29	65	65	53	**10**
	W	Check that there are no horizontal pipelines for supply or drainage run above the false ceiling.	29	28	33	30	**20**
	X	Check that all pipelines have the right diameter, especially the main riser of water supply and the drainage system.	53	14	37	34.7	**26**
	Y	Check that the design provides for shutoff valves for each hot and cold riser, as well as for all branches.	45	77	43	55	**9**
	Z	Check that the design provides for manholes for maintaining and cleaning the sewage system, especially at the corners.	58	42	32	44	**17**
	A*	Check that the design provides for two different drainage lines of waste water; one for gray water and one for hand washing in order to store.	60	8	16	28	**31**
	B*	Check that the design provides for sufficient numbers of drainage traps at the roof.	60	48	50	52.7	**12**
	C*	Check that the design provides for cleanouts at both the ground and roof levels to filter any soil out from the storm water drains.	63	8	45	38.7	**21**
	D*	Check that the design provides for ventilating stacks to maintain both pressure and siphonage, and avoid foul air entering the space.	58	71	19	49.3	**14**

	E*	Check that there are no external drainage penetrates any parapets to avoid the development of moulds and stains on the façade.	54	32	30	38.7	**22**
	F*	Check that the design provides for drains in mechanical plant where spillage might occur.	55	3	74	44	**18**
	G*	Check that the design provides for supply pipelines for fire suppression purposes with appropriate pressure.	80	60	85	75	**4**
	H*	Check that the design provides for means of escape from fire in buildings.	95	69	102	88.7	**2**
	I*	Check that the design provides for appropriate systems for fire suppression, notification, and detection.	103	63	107	91	**1**
HVAC Concerns	J*	Check that the design provides for air conditioning supply to toilets and ablution areas. These locations should be maintained at negative pressure with properly sized exhaust/extract fans.	70	88	69	75.7	**3**
	K*	Check that the design provides for more than one chiller, as chillers will operate more efficiently near the peak loads.	80	22	34	45.3	**15**
	L*	Check that the design provides for a standby chiller that could be operated when other chillers are being serviced.	91	32	31	51.3	**13**
	M*	Check that the design provides for dividing the HVAC ducting distribution through valves for ease of maintenance.	67	26	21	38	**23**
	N*	Check that the design provides for adequate distance between supply and return diffusers as well as the fresh air intake and exhaust air.	64	71	36	57	**8**
	O*	Check that there is no intermixing of the exhaust air from	80	79	25	61.3	**6**

		kitchens and toilets with the fresh air intake from fresh air handling units.					
	P*	Check that the design provides for thermal and acoustical insulation for all air handling units and mechanical rooms.	68	39	12	39.7	**20**
	Q*	Check that the design provides for insulating all chilled water pipes to avoid any water leakages as well as condensation problems.	67	42	25	44.7	**16**

7.3 DATA CONSISTENCY

Sometimes, the judgments of the expert may be not consistent with one another. Ishizaka and Lusti (2006) discuss some of priorities derivation methods that are covered in the literature. These methods were divided into two group (Golany et al. 1993), namely the Eigen-value approach and the methods minimizing the distance between the user-defined matrix and the nearest consistent. The discussed methods are mean of normalized values, The Eigen-value approach and the geometric mean methods. Since The Eigen value approach is unclear by many authors, the power method is applied to Eigen-value method. This power method is based on iterative process. Due to this fact, it is not easy to perform this method manually, especially if the matrix is too large like our case, where the matrix is 43 X 43, the method is implemented through A matLab program for each experts' scoring matrix (appendix-C) . In order to understand this method, the first three concerns from the first expert's scoring matrix are taken as an example as illustrated in Table 7-3.

Table 7-3: Pair-wise comparison between the first three concerns from the first expert's scoring matrix

Concerns	Importance Scale 1-3	Concerns
Check that the architectural form of the building provides for ease of cleaning and maintenance of the fenestration. (A)	A-1	Check that basins of agriculture are located away from the facades to avoid dampness.(B)
Check that the architectural form of the building provides for ease of cleaning and maintenance of the fenestration (A)	C-3	Check that the design provides the kitchens and bathrooms with windows. (C)
Check that basins of agriculture are located away from the facades to avoid dampness.(B)	C-3	Check that the design provides the kitchens and bathrooms with windows.(C)

To check the consistency for these three concerns using the Eigen-value method, the comparisons are entered into a 3X3 matrix as illustrated in Figure 7.1. The diagonal of this matrix consists of all numeral ones, as the concern is equally important to itself. This matrix has reciprocal relationship, which means lower triangular are the inverse of upper triangular in the matrix.

	A	B	C
A	1/1	1/1	1/3
B	1/1	1/1	1/3
C	3/1	3/1	1/1

Figure 7.1: The original matrix developed from table 7.3

The pair-wise scoring matrix is converted to decimal value, as illustrated in Figure 7.2. After that this matrix is squared (O^2) as illustrated in Figure 7.3.

	A	B	C
A	1	1	0.333
B	1	1	0.333
C	3	3	1

Figure 7.2: The original matrix developed- expressed in decimal values

	A	B	C
A	3	3	1
B	3	3	1
C	9	9	3

Figure 7.3: the original matrix after squaring

As illustrated in Figure 7.4 the Eigen-vector value calculated by summing the rows of the matrix, calculating the overall sum of these rows and normalizing the Eigen- value, the result is Eigen-Vector.

	A	B	C	Eigen Value	Eigen-Vector
A	3	3	1	= 7	0.2
B	3	3	1	= 7	0.2
C	9	9	3	= 21	0.6
			Total	= 35	1.000

Figure 7.4: Eigen- values and Eigen-vectors calculation for the first squaring

Since the power method applied to Eigen-value method is based on iterative process, the last step is repeated until the change in the resulting Eigen-vector from iteration to iteration is acceptable. According to Saaty (1980) 5% inconsistency is assumed. Figure 7.5 illustrates the process of second squaring (O^3) of the original matrix. Figure 7.6 illustrates the difference between the Eigen-vectors.

	A	B	C	Eigen Value	Eigen-Vector
A	9	9	3	= 21	0.2
B	9	9	3	= 21	0.2
C	27	27	9	= 63	0.6
			Total	= 105	1.000

Figure 7.5: Eigen- values and Eigen-vectors calculation for the second squaring

Eigen Vector (O^2)	Eigen-Vector (O^3)	Difference (O^2- O^3)
0.2	0.2	0.000
0.2	0.2	0.000
0.6	0.6	0.000

Figure 7.6: The difference between first and second matrix squaring Eigen-vector

From the last figure, the result is satisfying the inconsistency of < 0.05 from the first iteration. Since all the values are going to zero, this means that the matrix is completely consistent. But in other case, if the inconsistency is higher that assumed one, more iterations are required.

In our case, the matrix is 43X43, which means that, it is not easy to determine the consistency manually. MATLAB programs was written to facilitate the consistency calculation for the three expert's scoring matrix we have (Appendix-D). As mentioned before, the concept used in these programs is power method applied to Eigen-value method. The output of the first program (appendix-D) which serves the first expert's scoring matrix indicated the consistency range between (-0.0004) and (0.0003) which is less than 0.05 and obtained in one iteration. The output of the second program (appendix-D) which serves the second expert's scoring matrix indicated the consistency range between (-0.0001) and (0.0001) which is less than 0.05 and obtained in one iteration. The output of the third program (appendix-D) which serves the third expert's scoring matrix indicated the consistency range between (-0.0002) and (0.0003) which is less than 0.05 and obtained in one iteration.

7.4 THE CORRELATION BETWEEN THE EXPERTS AND DIRECTORS OF MAINTENANCE DIVISIONS

In this section, a correlation check for the ranking of the set of concerns at the design development stage (60% of project design) is performed. This check is between the three experts ranking and the directors of maintenance department's divisions (architectural, structural, electrical, mechanical, and HVAC) ranking.

7.4.1 Correlation

Correlation (r) is a term used to find the relation between different parties, and the degree of this relationship. There are three methods which are used to determine the correlation, these method are the spearman correlation, the partial correlation and the multiple correlation. Since we have two parties the spearman correlation is used (Al-Shiha, 1993).

7.4.1.1 The spearman correlation

The spearman correlation is used in order to find and compare how well two parties agree. The rank correlation coefficient (rho) is calculated using the following formula(Al-Hammad et al., 1997):

The rank correlation coefficient (r) = $1-\frac{6\sum D^2}{N(N^2-1)}$

Where:

D= Difference between the ranks given by the two parties for a particular concerns.

N = Number of concerns which is 43 concerns in this case.

The calucation of (D) values wish is the difference between the ranks given by one party and the rank given by another party for the same concerns is illustrated in .Table 7-4

Table 7-4: Calculation of D , D2 and the summation of D2 values for spearman rank correlation

Cat.	No..	Set Of Concerns at 60% of Project Design	Rank (Expert)	Rank (Engineer)	D	D^2
Architectural Concerns	A	Check that the architectural form of the building provides for ease of cleaning and maintenance of the fenestration.	39	39	0	0
	B	Check that basins of agriculture are located away from the facades to avoid dampness	41	19	22	484
	C	Check that the design provides the kitchens and bathrooms with windows.	40	43	3	9
	D	Check the provision of enough areas for exhaust and service shafts of kitchens and bathroom	32	36	4	16
	E	Check that the design provides access for fire fighting and egress routes.	5	1	4	16
Structural Concern	F	Check that the results of the soils bearing capacity tests are taken into consideration in the design of the foundation system.	19	23	4	16
	G	Check that the design provides for the required strength, thickness, and fire resistance rating of building construction materials	28	33	5	25

Electrical Concerns	H	Check that the main board of circuit breakers is placed in a safe and visible location.	**37**	**9**	**28**	**784**
	I	Check that the design provides for a circuit breaker for each power plug in kitchens as well as for all room light switches.	**34**	**16**	**18**	**324**
	J	Check that the design provides for a sufficient number of luminaries to provide the required illumination intensity.	**35**	**28**	**7**	**49**
	K	Check that the design provides for lighting switches adjacent to access points.	**29**	**26**	**3**	**9**
	L	Check that the design provides for lighting in the elevator shaft.	**43**	**40**	**3**	**9**
	M	Check that the design provides for a sufficient number of power plugs to avoid the use of extension cords.	**27**	**20**	**7**	**49**
	N	Check that the design provides for a fan coil unit - with single point electrical connection box - for power supply and control.	**42**	**34**	**8**	**64**
	O	Check that the designer provides for clear cable management and identification	**36**	**30**	**6**	**36**
	P	Check that the designer provides for communication and internet lines to the all spaces in the building	**33**	**37**	**4**	**16**
	Q	Check that the design provides for backup power supply, emergency lighting, and address wiring of fire notification systems, and detection systems	**25**	**27**	**2**	**4**
	R	Check that the provided communication internet lines are away from power and lighting lines	**38**	**32**	**6**	**36**
	S	Check that the design provides for grounding systems.	**7**	**13**	**6**	**36**

Mechanical Concerns	T	Check that there are no pipelines penetrating the walls or the roof.	**11**	**10**	**1**	**1**
	U	Check that the design provides for a complete layout for all the pipelines.	**24**	**21**	**3**	**9**
	V	Check that all the supply pipelines are not running through the slabs.	**10**	**11**	**1**	**1**
	W	Check that there are no horizontal pipelines for supply or drainage run above the false ceiling.	**20**	**17**	**3**	**9**
	X	Check that all pipelines have the right diameter, especially the main riser of water supply and the drainage system.	**26**	**7**	**19**	**361**
	Y	Check that the design provides for shutoff valves for each hot and cold riser, as well as for all branches.	**9**	**2**	**7**	**49**
	Z	Check that the design provides for manholes for maintaining and cleaning the sewage system, especially at the corners.	**17**	**14**	**3**	**9**
	A*	Check that the design provides for two different drainage lines of waste water; one for gray water and one for hand washing in order to store.	**31**	**35**	**4**	**16**
	B*	Check that the design provides for sufficient numbers of drainage traps at the roof.	**12**	**31**	**19**	**361**
	C*	Check that the design provides for cleanouts at both the ground and roof levels to filter any soil out from the storm water drains.	**21**	**41**	**20**	**400**
	D*	Check that the design provides for ventilating stacks to maintain both pressure and siphonage, and avoid foul air entering the space.	**14**	**24**	**10**	**100**

	E*	Check that there are no external drainage penetrates any parapets to avoid the development of moulds and stains on the façade.	**22**	**42**	**20**	**400**
	F*	Check that the design provides for drains in mechanical plant where spillage might occur.	**18**	**38**	**20**	**400**
	G*	Check that the design provides for supply pipelines for fire suppression purposes with appropriate pressure.	**4**	**18**	**14**	**196**
	H*	Check that the design provides for means of escape from fire in buildings.	**2**	**29**	**27**	**729**
	I*	Check that the design provides for appropriate systems for fire suppression, notification, and detection.	**1**	**4**	**3**	**9**
HVAC Concerns	J*	Check that the design provides for air conditioning supply to toilets and ablution areas. These locations should be maintained at negative pressure with properly sized exhaust/extract fans.	**3**	**1**	**2**	**4**
	K*	Check that the design provides for more than one chiller, as chillers will operate more efficiently near the peak loads.	**15**	**15**	**0**	**0**
	L*	Check that the design provides for a standby chiller that could be operated when other chillers are being serviced.	**13**	**25**	**12**	**144**
	M*	Check that the design provides for dividing the HVAC ducting distribution through valves for ease of maintenance.	**23**	**12**	**11**	**121**
	N*	Check that the design provides for adequate distance between supply and return diffusers as well as the fresh air intake and exhaust air.	**8**	**8**	**0**	**0**
	O*	Check that there is no intermixing of the exhaust air from	**6**	**5**	**1**	**1**

		kitchens and toilets with the fresh air intake from fresh air handling units.				
	P*	Check that the design provides for thermal and acoustical insulation for all air handling units and mechanical rooms.	**20**	**22**	**2**	**4**
	Q*	Check that the design provides for insulating all chilled water pipes to avoid any water leakages as well as condensation problems.	**16**	**6**	**10**	**100**
					Summation of D^2	**5406**

The rank correlation coefficient for the concerns after substituting in the previous formula is equal 0.592. This means that the agreement between the experts and the directors of maintenance mangers (r) is about 60%.

7.4.2 Test of Correlation

In order to test the hypothesis that there is an agreement between the experts and the directors of maintenance mangers, the ‘t’ test is used in this study. t-value is calculated using the following formula (Al-Hammad et al., 1997):

$$t = [\ (n - 2) * r^2 / (1 - r^2)^2\ ]^{½}$$

Where:

r= the spearman correlation

n = the number of observation (the number of concerns in this study).

From the formula, the value of ‘t’ equals 4.7. The ‘t’ test at 95 percent confidence level of the null hypothesis is tested by comparing the t value with the critical test value. From the tables of t- distribution (Hoel, 1971) the $t_{0.05,}\ \infty$ equals 1.645.

In our case, the calculated value of ‘t’ is greater than the critical value. This means that the null hypothesis is rejected and establishes the fact that the two parties are in agreement on the ranking of the concerns.

7.5 DISCUSSION

This section presents a discussion of the results pertaining to pair-wise comparison for the set of concerns at design development stage (60% of project design). Pair-wise comparisons were carried out three times by three different experts. The three comparisons aimed at ranking these concerns due to their priority. As illustrated in Table 7-2, the five concerns “Check that the design provides for appropriate systems for fire suppression, notification, and detection”, “Check that the design provides for means of escape from fire in buildings”, “Check that the design provides for air conditioning supply to toilets and ablution areas. These locations should be maintained at negative pressure with properly sized exhaust/extract fans”, “Check that the design provides for supply pipelines for fire suppression purposes with appropriate pressure” and “Check that the design provides access for fire fighting and egress routes” received the highest ranking respectively. It is believed that this ranking of priorities is highly reasonable due to the fact that the most important concerns in the buildings are the human safety and human comfort.

The results of the consistency check indicate that none of the scoring matrixes required second iteration to get the consistency to be 0.05. This is due to the fact that a thorough explanation was provided to the three experts who carried out the pair-wise comparisons, and they have a plenty of experience.

Moreover, it worth mentioning that all the scoring matrixes are consistent from the first iteration, because of the scale that was used in these matrixes as illustrated in Table 7-1 (i.e. 1-3). This scale gives small different compared with the analytical hierarchy process (AHP) that has long scale (i.e. 1-9).

Using a ‘t’ test at 95% confidence level of the null hypothesis show that there is an agreement between the three experts and the directors of maintenance department’s divisions (architectural, structural, electrical, mechanical, and HVAC) on the ranking of the concerns.

CHAPTER 8

CONCLUSION AND RECOMMENDATION

8.1 BACKGROUND

This research aimed at developing a framework for the involvement of the maintenance manager during the design development and review stages. To develop this framework, pair-wise comparison was carried out by three maintenance managers as subject matter experts to determine the rank of the identified and assessed concerns and/or details raised by the maintenance manger during the design development stage (60% of project design) which is the most significant project design stage. In this chapter, a summary of the research is presented, followed by conclusions derived from the research and recommendations for future studies.

8.2 SUMMARY OF THE RESEARCH STUDY

This research is divided into eight chapters. The summary of this research is as follows:

- The first chapter (Introduction) introduces the domain area of the research (facilities maintenance management). It includes a statement of the problem, the objectives of the study, its scope and limitations, significance of the study and research methodology.

- The second chapter (Literature Review) summarizes the literature related to traditional construction project process, design effects on facility operation and maintenance, design defects in buildings, Definition of maintainability, why maintainability is important, how to improve the maintainability of the buildings and previous studies about the involvement of maintenance manager during design phase.

- The third chapter (Operation and Maintenance Problems) provides a thorough identification for the most significant 66 operation and maintenance problems that commonly emerge as a consequence of the maintenance manager’s lack of involvement during the design development and review stages. These problems were classified under five groups, namely architectural design problems, structural design problems, electrical design problems, mechanical design problems, and HVAC. Identification of these factors was carried out based on review of the published literature and interviews with the maintenance department’s engineers of two universities, namely King Fahd University of Petroleum and Minerals and Dammam University.

- The fourth chapter (Set of Concerns and/or Details) presents the identification of the 85 major of concerns and/or details raised by the maintenance manager during the design development and review stages at different project design stages (i.e. 30%, 60% and 90%), which impacts on building maintainability in the future. These concerns and/or details were classified under five categories, namely architectural major concerns and/or details, structural major concerns and/or details, electrical major concerns and/or details, mechanical major concerns and/or details, and HVAC major concerns and/or details. Identification of these concerns was carried out based on review of the published literature and interviews with the maintenance department's engineers of two universities, namely King Fahd University of Petroleum and Minerals and Dammam University.

- The fifth chapter (Data Analysis and Results) presents the development of the questionnaire survey, pilot- testing of the questionnaire survey, distribution of the questionnaire to the selected sample of 13 public Saudi Arabian universities. Part I of the questionnaire aimed at ranking the operation and maintenance problems under the different categories and set of concerns and/or details under its different categories. Analysis of data obtained through Part I of the questionnaire survey was the main pat in this chapter. The results received from this part of the questionnaire were analyzed and the importance index and the rank for each operation and maintenance problem and set of concerns were identified. These results are utilized to achieve the first and the second objectives of the study.

- The sixth chapter (Investigation of the Current Practices of the Maintenance Manager's Involvement) presents data analysis for Part II of the questionnaire survey which contained 10 different questions about the maintenance manager's current practices. The results obtained from this part of the questionnaire were analyzed and the current practices of the maintenance manger's involvement were determined. These results are utilized to achieve the third objective of this study.

- The seventh chapter (A Framework to Prioritize Major Concern at the Most Significant Project Design Stage) aimed at developing a framework to prioritize the major concerns and /or details raised by the maintenance manager during the design development and review stages at the most significant project design stags (60% of project design). This stage was determined by question #10 in part II of questionnaire survey (chapter six). The pair-wise comparisons for the 43 major concerns and/ or details at design development stage (60%of project design) were carried out by three experts in the criteria scoring matrix. Then, the criteria scoring matrix for each expert was evaluated to obtain the overall rank of each identified major concern and/or detail. MATLAB program was written to facilitate the calculation of data consistency. As presented in this chapter, all the judgments in the scoring matrix consistency were not more than (0.05).

8.3 CONCLUSIONS

- Under the group of architectural design problem, the two problems "Inability to maintain vertical risers due to the limited areas of the service shafts" and "Signs of stains and seepage due to improper rainwater drainage around windows" received the highest importance index values of 91.67% (E.I) and 79.17% (V.I), respectively.

- Under the group of structural design problems, the two problems “Plaster crack between concrete brick joints and wall-floor joints and “Damage to underground pipelines due to the settlement of soil and foundations” received the highest importance index values of 77.08% (V.I) and 72.92% (V.I), respectively.

- Under the group of electrical design problems, the two problems “Exposed cabling and loose connections” and “Exposed plugs at open and wet areas” received the highest importance index values of 89.58% (E.I) and 85.42% (V.I), respectively.

- Under the group of mechanical design problems, the two problems “Absence of detection and notification systems at hazardous areas” and “Absence of appropriate fire suppression systems” received the highest importance index values of 97.92% (E.I) and 89.58% (E.I), respectively.

- Under the group of HVAC design problems, the two problems “Inadequacy of the HVAC system to provide the required comfort zone temperature” and “Poor indoor air quality that may cause infectious diseases and respiratory illnesses due to insufficient provision of fresh air” received the highest importance index values 87.5% (E.I) and 85.42% (V.I), respectively.

- Both “Mechanical design problems” and “HVAC design problem” received the highest average importance index values.

- Under the group of architectural major concerns (at 30% of project design), the two concerns and/or details “Check that the design considers access for the handicapped in terms of provision of suitable parking, emergency egress routes, toilets, ramps for circulation, and suitable elevator panels” and “Check that the design takes into account the ability to accommodate future changes in the layout as demanded by clients”, received the highest importance index values of 95.83% (E.I) and 79.17% (V.I), respectively.

- Under the group of structural major concerns (at 30% of project design), “Check that the design provides for expansion joints when the length of the building exceeds that length specified by the codes”. It received an importance index of 81.25% (V.I).

- Under the group of HVAC major concerns (at 30% of project design), the two concerns and/or details “Check that the cooling towers are located away from the adjacent buildings to eliminate background noise and emissions of mist” and “Check that the design provides access for reaching cooling towers, chillers, and condensers for maintenance” received the highest importance index values of 81.25% (V.I) and 79.17% (V.I), respectively.

- The structural major concerns and/or details raised by the maintenance manages at 30% of project design received the highest average importance index value of 81.25% (V.I) and was ranked as the first group in importance.

- Under the group of architectural major concerns (at 60% of project design), the two concerns and/or details “Check that the design provides access for fire fighting and egress routes” and “Check that basins of agriculture are located away from the facades to avoid dampness” received the highest importance index values of 95.83% (E.I) and 82.25% (V.I), respectively.

- Under the group of structural major concerns (at 60% of project design), the two concerns and/or details “Check that the results of the soils bearing capacity tests are taken into consideration in the design of the foundation system” and “Check that the design provides for the required strength, thickness, and fire resistance rating of building construction materials” received the importance index values of 79.17% (V.I) and 68.75% (V.I), respectively.

- Under the group of electrical major concerns (at 60% of project design), the two concerns and/or details “Check that the main board of circuit breakers is placed in a safe and visible location” and “Check that the design provides for grounding systems” received the highest importance index values of 87.5% (E.I) and 85.42% (V.I), respectively.

- Under the group of mechanical major concerns (at 60% of project design), the two concerns and/or details “Check that the design provides for shutoff valves for each hot and cold riser, as well as for all branches” and “Check that the design provides for appropriate systems for fire suppression, notification, and detection” received the highest importance index values of 95.83% (E.I) and 93.75% (E.I), respectively.

- Under the group of HVAC major concerns (at 60% of project design), the two concerns and/or details "Check that the design provides for air conditioning supply to toilets and ablution areas, these locations should be maintained at negative pressure with properly sized exhaust/extract fans" and "Check that there is no intermixing of the exhaust air from kitchens and toilets with the fresh air intake from fresh air handling units" received the highest importance index values of 95.83% (E.I) and 93.75% (E.I), respectively.

- The group of the HVAC major concerns and/or details raised by the maintenance managers at 60% of project design received the highest average importance index between the five groups.

- Under the group of architectural major concerns (at 90% of project design), the two concerns and/or details "Check that all the materials specified by the design professionals are available at the markets at that time" and "Check that the design documents and specifications provides for exterior doors that swing outward." received the highest importance index values of 85.42% (V.I) and 79.17% (V.I), respectively.

- Under the group of structural major concerns (at 90% of project design), the two concerns and/or details "Check that the specification provides for appropriate fireproofing and fire stopping materials in the building" and "Check that the specifications provide for adequate concrete cover for the steel reinforcement as specified by codes" received the highest importance index values of 91.67% (E.I) and 87.5% (E.I), respectively.

- Under the group of electrical major concerns (at 90% of project design), the two concerns and/or details “Check that the specifications provides for the right diameter of cabling for the lighting system as well as for power plugs” and “Check that the specifications provide fluorescent ballasts that are electronic, high frequency, and of rapid start with no sound” received the importance values of 93.75% (E.I) and 77.08% (V.I), respectively.

- Under the group of mechanical major concerns (at 90% of project design), the two concerns and/or details “Check that the specifications provide for the sealant type that will be used in filling the expansion joints” and “Avoid the specification of any unreinforced PVC at any exposed envelopes to solar radiation” received the highest importance index values of 83.33% (V.I) and 81.25% (V.I), respectively.

- Under the group of HVAC major concerns (at 90% of project design) The two concerns and/or details “Check that the design provides a complete set of drawings and details of the fire/smoke system interlocking with the HVAC system” and “Check that the design provides a complete set of drawings and details for the air handling units, fan coil units, exhaust fans, fire/smoke system and the cooling tower plant” received the highest importance index values of 93.75% (E.I) and 91.67% (E.I), respectively.

- The group of the electrical major concerns and/or details raised by the maintenance managers at 90% of project design received the highest average importance index between the five groups.

- 83% of the respondents (10 out of 12 respondents) to the questionnaire survey indicated that they have been involved or consulted during the design development and review stages in one way or another.

- 80% of the respondents (8 respondents) are involved indirectly with the integrated design team. Among the 8 respondents who have been involved indirectly, 87.5% of the respondents (7 out of 8 respondents) have been involved indirectly through the project management department that acts as an interface between maintenance manager and the integrated design team.

- 62.5% (5 respondents) provide feedback through commenting on a copy of the design documents sent for review.

- 7 respondents (70% of the respondents) have been requested to provide feedback during the final documents stage (100% design completion). It is believed that this involvement with the integrated design team would be too late to provide practical feedback that can be incorporated in the design documents.

- 60% of the respondents (6 respondents) ensure that their feedback has been taken into consideration through reviewing the final design documents at 100% completion.

- 60% of the respondents (6 respondents) provide feedback on drawings and specifications for particular divisions of work. Among the 6 respondents who provide feedback on drawings and specifications for particular divisions of work, all the respondents (100%) provide feedback on the HVAC division.

- 9 out of 10 respondents (90% of the respondents) provide their feedback in the form of reviewing of the appropriateness of the systems type and performance data.

- All the respondents (100%) provide feedback based on experience acquired through receiving complaints from users.

- 90% of the respondents (9 out of 10) select design development stage (60% of project design) as the most significant design stage review that will result in a significant reduction in future maintenance works.

- Pair-wise comparisons were carried out by three experts into three different scoring matrixes. The result was ranking these concerns due to its priority. The five concerns “Check that the design provides for appropriate systems for fire suppression, notification, and detection”, “Check that the design provides for means of escape from fire in buildings”, “Check that the design provides for air conditioning supply to toilets and ablution areas. These locations should be maintained at negative pressure with properly sized exhaust/extract fans”, “Check that the design provides for supply pipelines for fire suppression purposes with appropriate pressure” and “Check that the design provides access for fire fighting and egress routes” received the highest rank respectively.

- It is indicated that none of the scoring matrixes required second iteration to get the consistency (0.05). This due to the fact that the three experts who carried out the pair-wise comparisons have enough experience, and are very consistent in giving priority.

- Using a ‘t’ test at 95% confidence level of the null hypothesis show that there is an agreement between the three experts and the directors of maintenance department’s divisions (architectural, structural, electrical, mechanical, and HVAC) on the ranking of the concerns.

8.4 RECOMMENDATIONS

- The identified set of concerns and/or details are beneficial to both the academic researchers and practitioners.

- This study has the potential to raise awareness among the built-environment community in Saudi Arabia about the interaction and the communication between the maintenance manager and the integrated design team (Architect, Civil, Structure, Electrical, Mechanical, etc.) throughout the design phase.

- It is significant to involve the maintenance manager in the early design decisions of building projects. Such involvement would result in reducing the challenges faced during the operation and maintenance phase.

- The analysis of pair-wise comparison of the set of concerns and/or details at the most significant project design stage showed that the important aspects in building design are occupants' safety and human comfort.

8.5 DIRECTION FOR FUTURE WORK

For future research, it is recommended that a thorough survey be conducted on different types of buildings such as office buildings, residential, industrial and sports' facilities in Saudi Arabia. This is mainly due to the fact that different types of buildings portray different characteristics in terms of design and followed maintenance procedures.

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APPENDIX – A (QUESTIONNAIRE SERVEY)

King Fahd University of Petroleum and Minerals
College of Environmental Design
Architectural Engineering Department

Dear Sir,

Subject: **Study of the Involvement of the Maintenance Manager during the Design Development and Review Stages.**

A study is being conducted on the importance of maintenance manager's involvement during the design development and review stages of building projects. The objectives of the researcher are to identify and assess the most significant operation and maintenance problems, to investigate the current practice of the maintenance manager involvement, and lastly to identify and assess the most important concerns and/or details that raised by maintenance manager and should take during the design development and review stage.

The enclosed questionnaire consists of two parts**:**

Part one which divided into five sections: every single section includes, (A) general information about the respondents and the (B) respondent's assessment of (B1) operation and maintenance problems, (B2) and the set of concerns and/or details raised by the maintenance manager during the design development and review stages that will have significant impacts on building maintainability in the future,

These five sections must be completed by directors of these following maintenance divisions respectively: architecture, civil, electrical, mechanical, and HVAC.

Part two includes general information about the respondent, and a series of questions to investigate the current practice of the involvement.

This part must be completed by Maintenance division's manager

Your cooperation in filling this questionnaire is appreciated. Please be noticed that the information will strictly be used for educational purposes, and will be kept secret
Please return this questionnaire once filled to the following address:

Mr. Fadi Abelrazzaq Fatayer
Architectural Engineering Department
King Fahd University of Petroleum and Minerals
Dhahran 31261
P.O box 8633
Saudi Arabia
E-mail: fatayer@kfupm.edu.sa
Mobile: 0591102576

Part I of questionnaire

Section I: This section must be completed by the Director of the Architecture Maintenance Division

A. General Information

Please tick (✓) your answer and fill in the blanks accordingly

1- Respondent Information

Name (Optional)	
Telephone no (Optional)	
Facsimile (Optional)	
E-Mail Address (Optional)	

2- How long have you been working in the maintenance department?

Less than 5 years		5-10 years	
10-20 years		More than 20 years	

3- Are you interested in receiving a summary of the finding of this study?

Yes		No	

4- If yes, Please indicates your address (if you not provide it at the first question)

____

B. Respondent assessment

B1. Assessment of the most important operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during architectural design development and review stages

Please rate the degree of importance of each of the identified operation and maintenance problems by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any operation and maintenance problem that can enhance the research and rate it according to the evaluation terms provided above.

Operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during architectural design development and review stages		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Inability to entirely reach and maintain the fenestration due to the architectural form of the building.					
2.	Insufficient availability of specific building materials in the market when replacement of the same is required.					
3.	Inappropriate selection and specification of specific building material for incorporation in the project.					
4.	Propagation of foul odor due the placement of kitchens and toilets in the direction of the prevailing wind.					
5.	Design and placement of large windows in building elevations facing the solar path.					
6.	Difficulty in moving the furniture and equipment within interior spaces due to the limited width and height of doors.					
7.	Wall edges that could chip due to impacts of loads and occupants.					
8.	Specification of low quality tiles that could be heavily stained or degraded due to heavy human traffic and weather condition.					
9.	Signs of stains and seepage due to improper rainwater drainage around windows.					
10.	Visibility of signs of stains and development of moulds due to inadequate means of ventilation (natural or mechanical or a combination of both).					
11.	Signs of stains on the building façade due to the different levels of moisture absorption of building materials.					
12.	Moisture and vapors traveling from wet to dry areas.					
13.	Plaster decay on external wall surface due to dampness.					
14.	Specification of dark color paint as an exterior finish in hot, arid and dusty regions.					
15.	Paint peeling, flaking, blistering, biological attack and efflorescence.					
16	Inability to maintain vertical risers due to the limited areas of the service shafts.					
Other (Please specify)						

B2. Assessment of the major concerns and/or details raised by the maintenance manager during architecture design development and review stages which will have significant impacts on building maintainability in the future

Please rate the degree of importance of each of the identified concerns and/or details by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any concerns and/or details that can enhance the research and rate it according to the evaluation terms provided above.

	Major Concerns and/or details raised by the maintenance manager during the architectural design development and review stages	**Assessment**				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
A. At 30% of the project design						
1.	Check that the design considers the orientation of the building and the wind load effect on the building envelops and interior spaces.					
2.	Check that the areas of the windows are appropriate for the prevailing climate and orientation of the building.					
3.	Check that the dimensions of the doors and windows could accommodate movement of furniture.					
4.	Check that the design considers access for the handicapped in terms of provision of suitable parking, emergency egress routes, toilets, ramps for circulation, and suitable elevator panels.					
5.	Check that the design takes into account the ability to accommodate future changes in the layout as demanded by clients.					
6.	Check that all building materials are suitable for the local climate, especially for building envelopes.					
7.	Check that the designer provides intermediate lobby between the outdoor and indoor areas to work as moisture and temperature trapping zone.					
Other (Please specify)						

		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
B.	**At 60% of the project design**					
1.	Check that the architectural form of the building provides for ease of cleaning and maintenance of the fenestration.					
2.	Check that basins of agriculture are located away from the facades to avoid dampness					
3..	Check that the design provides the kitchens and bathrooms with windows.					
4.	Check the provision of enough areas for exhaust and service shafts of kitchens and bathroom					
5.	Check that the design provides access for fire fighting and egress routes.					
Other (Please specify)						
C.	**At 90% of the project design**					
1.	Check that all the materials specified by the design professionals are available at the markets at that time.					
2.	Check that the design documents and specifications provides for exterior doors that swing outward.					
3.	Check that the design of the building envelope provides for ease of replacement of systems and subsystems.					
4.	Check that the specified type and the commercial brand of paint is reliable.					
5.	Check that the specified type of tiles is wear and abrasion resistant.					
6.	Check that the design provides for metal, wood, plastic or rubber walls edges around sharp corners.					
7.	Check that the design and specification provides for a vapor barrier or retarder on the warm side of the wall to avoid internal condensation.					
8.	Check that the design provides a complete set of drawings and details of thermal insulations for walls and roof.					
9.	Check that the design provides for a detailing of waterproofing system to prevent leaks and hence deterioration of steel reinforcement.					
10.	Check that the specified type and the commercial brand of waterproofing are reliable.					
Other (Please specify)						

Section II: This section must be completed by the Director of Structural Maintenance Division

A. General Information

Please tick (✓) your answer and fill in the blanks accordingly

1- Respondent Information

Name (Optional)	
Telephone no (Optional)	
Facsimile (Optional)	
E-Mail Address (Optional)	

2- How long have you been working in the maintenance department?

Less than 5 years		5-10 years	
10-20 years		More than 20 years	

3- Are you interested in receiving a summary of the finding of this study?

Yes		No	

4- If yes, Please indicate your address (if you not provide it at the first question)

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B. Respondent assessment

B1. Assessment of the most important operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during structural design development and review stages

Please rate the degree of importance of each of the identified operation and maintenance problems by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any operation and maintenance problem that can enhance the research and rate it according to the evaluation terms provided above.

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during structural design development and review stages		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Signs of cracks around columns and beams due to inadequate structural design.					
2.	Cracks in floor slabs, walls, and tiles due to differential settlement.					
3.	Corrosion of steel reinforcement bars due to Insufficient concrete cover.					
4.	Tile deponding, adhesive failure, cracks and fraction at weak points due to expansion and contraction stresses.					
5.	Moisture and dirt infiltration through expansion joints due to inefficient filling materials and sealant.					
6.	Sign of moisture penetration in the basement at beam-wall joints, walls, and ceiling-wall joints due to insufficient waterproofing and insulation.					
7.	Damage to underground pipelines due to the settlement of soil and foundations.					
8.	Plaster crack between concrete brick joints and wall-floor joints.					
Other (Please specify)						

B2. Assessment of the major concerns and/or details raised by the maintenance manager during structural design development and review stages which will have significant impacts on building maintainability in the future

Please rate the degree of importance of each of the identified concerns and/or details by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any concerns and/or details that can enhance the research and rate it according to the evaluation terms provided above.

Major Concerns and/or details raised by the maintenance manager during structural design development and review stages		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
A. At 30% of the project design						
1.	Check that the design provides for expansion joints when the length of the building exceeds that length specified by the codes					
B. At 60% of the project design						
1.	Check that the results of the soils bearing capacity tests are taken into consideration in the design of the foundation system.					
2.	Check that the design provides for the required strength, thickness, and fire resistance rating of building construction materials					
C. At 90% of the project design						
1.	Check that the design provides for strict specifications for the procurement of concrete.					
2.	Check that the specifications provide for adequate concrete cover for the steel reinforcement as specified by codes.					
3.	Check that the specifications provide for a mesh between concrete brick joints and floor wall joints to avoid any future cracks.					
4.	Check that the specification provide for a full soil compaction (if required) to avoid future settlement.					
5.	Check that the specification provides for appropriate fireproofing and firestopping material in the building.					
Other (Please specify)						

<u>Section III</u>: This section must be completed by the Director of Electrical Maintenance Division

A. <u>General Information</u>

Please tick (✓) your answer and fill in the blanks accordingly

1. Respondent Information

Name (Optional)	
Telephone no (Optional)	
Facsimile (Optional)	
E-Mail Address (Optional)	

2. How long have you been working in the maintenance department?

Less than 5 years		5-10 years	
10-20 years		More than 20 years	

3. Are you interested in receiving a summary of the finding of this study?

Yes		No	

4. If yes, Please indicate your address (if you not provide it at the first question)

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B. <u>Respondent assessment</u>

B1. Assessment of the most important operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during electrical design development and review stages

Please rate the degree of importance of each of the identified operation and maintenance problems by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any operation and maintenance problem that can enhance the research and rate it according to the evaluation terms provided above.

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during the electrical design development and review stages (power, lighting, and communication cables)		**Assessment**				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Short circuits due to overload occurrence in plug points.					
2.	Insufficient number and distribution of plugs points..					
3.	Total power cut from one fault.					
4.	Exposed cabling and loose connections					
5.	Exposed Plugs at open and wet areas.					
6.	Flickering and blinking of fluorescent lamps.					
7.	Placement of light switches far away from access points.					
8.	Inadequate provision of the required illumination intensity.					
9.	Inability to reach high ceiling locations for the purpose of changing or cleaning fused light bulbs.					
10.	Inability to reach and maintain the main board of circuit breakers placed in invisible locations.					
11.	Convergence low voltage cabling with high voltage cabling in the same ducts					
12.	Total power and lighting cutoff when fire occurs (Notification systems will not operate in other places)					
13.	Effect of lightning on electrical appliances. (absence of grounding systems)					
Other (Please specify)						

B2. Assessment of the major concerns and/or details raised by the maintenance manager during electrical design development and review stages which will have significant impacts on building maintainability in the future

Please rate the degree of importance of each of the identified concerns and/or details by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any concerns and/or details that can enhance the research and rate it according to the evaluation terms provided above.

Major Concerns and/or details raised by the maintenance manager during the electrical design development and review stages (power, lighting, and communication cables)		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
A. At 60% of the project design						
1.	Check that the main board of circuit breakers is placed in a safe and visible location.					
2.	Check that the design provides for a circuit breaker for each power plug in kitchens as well as for all room light switches.					
3.	Check that the design provides for a sufficient number of luminaries to provide the required illumination intensity.					
4.	Check that the design provides for lighting switches adjacent to access points.					
5.	Check that the design provides for lighting in the elevator shaft.					
6.	Check that the design provides for a sufficient number of power plugs to avoid the use of extension cords.					
7.	Check that the design provides for a fan coil unit - with single point electrical connection box - for power supply and control.					
8.	Check that the designer provides for clear cable management and identification					
9.	Check that the designer provides for communication and internet lines to the all spaces in the building					
10.	Check that the design provides for backup power supply, emergency lighting, and address wiring of fire notification systems, and detection systems					
11.	Check that the provided communication internet lines are away from power and lighting lines					
12.	Check that the design provides for grounding systems.					
Other (Please specify)						

		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
B.	**At 90% of the project design**					
1.	Check that the specifications provide fluorescent ballasts that are electronic, high frequency, and of rapid start with no sound.					
2.	Check that the specifications provides for the right diameter of cabling for the lighting system as well as for power plugs.					
Other (Please specify)						

<u>Section IV</u>: This section must be completed by the Director of Mechanical Division

A. General Information

Please tick (✓) your answer and fill in the blanks accordingly

1. Respondent Information

Name (Optional)	
Telephone no (Optional)	
Facsimile (Optional)	
E-Mail Address (Optional)	

2. How long have you been working in the maintenance department?

Less than 5 years		5-10 years	
10-20 years		More than 20 years	

3. Are you interested in receiving a summary of the finding of this study?

Yes		No	

4. If yes, Please indicate your address (if you not provide it at the first question)

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B. Respondent assessment

B1. Assessment of the most important operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during mechanical design development and review stages

Please rate the degree of importance of each of the identified operation and maintenance problems by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any operation and maintenance problem that can enhance the research and rate it according to the evaluation terms provided above.

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during the mechanical design development and review stages (water supply system, sewage system, vertical transportation, and fire system)		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Inability to reach and maintain pipelines as a result of inappropriate layout of the fitting as well as horizontal runs of pipeline in slabs.					
2.	Inability to distinguish between the pipes servicing the different mechanical systems.					
3.	Water ponds on roofs due to the unavailability of drainage systems.					
4.	Slow sewer drainage due to insufficient diameter of stacks.					
5.	Inability to reach and maintain the sewer lines due to insufficient provision of manholes at corner points.					
6.	Propagation of foul odors due to the absence of ventilation vents.					
7.	Leakage through floor trap due to improper selection of the types of the waterproofing membrane.					
8.	Water leakage due to pipelines penetration through walls or floos.					
9.	Noise and turbulent flow in pipelines due to insufficient diameter.					
10.	Inadequate supply of water due to the insufficient diameter of pipelines and head pressure.					
11.	Complete cut of water supply in the building due to the absence of shut off valves that enable part of supply water to be closed when maintenance is required.					
12.	Corrosion of cast iron pipelines.					
13.	Moulds growth and stains on the façade due to the use of external drainage that penetrates the parapet.					
14.	Fungi and mould growth around the bathtub edges due to the use improper type of sealants.					
15.	Signs of cracks in wall plaster or tiles due to the use of suspended water closets.					
16.	Absence of detection and notification systems at hazardous areas.					
17.	Absence of appropriate fire suppression systems.					
Other (Please specify)						

B2. Assessment of the major concerns and/or details raised by the maintenance manager during mechanical design development and review stages which will have significant impacts on building maintainability in the future

Please rate the degree of importance of each of the identified concerns and/or details by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any concerns and/or details that can enhance the research and rate it according to the evaluation terms provided above.

	Major Concerns and/or details raised by the maintenance manager during the mechanical design development and review stages (water supply system, sewage system, fire system)	**Assessment**				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
	A. At 60% of the project design					
1.	Check that there are no pipelines penetrating the walls or the roof.					
2.	Check that the design provides for a complete layout for all the pipelines.					
3.	Check that all the supply pipelines are not running through the slabs.					
4.	Check that there are no horizontal pipelines for supply or drainage run above the false ceiling.					
5.	Check that all pipelines have the right diameter, especially the main riser of water supply and the drainage system.					
6.	Check that the design provides for shutoff valves for each hot and cold riser, as well as for all branches.					
7.	Check that the design provides for manholes for maintaining and cleaning the sewage system, especially at the corners.					
8.	Check that the design provides for two different drainage lines of waste water; one for gray water and one for hand washing in order to store.					
9.	Check that the design provides for sufficient numbers of drainage traps at the roof.					
10.	Check that the design provides for cleanouts at both the ground and roof levels to filter any soil out from the storm water drains.					
11.	Check that the design provides for ventilating stacks to maintain both pressure and siphonage, and avoid foul air entering the space.					
12.	Check that there are no external drainage penetrates any parapets to avoid the development of moulds and stains on the façade.					
13.	Check that the design provides for drains in mechanical plant where spillage might occur.					

		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
14.	Check that the design provides for supply pipelines for fire suppression purposes with appropriate pressure.					
15.	Check that the design provides for means of escape from fire in buildings.					
16.	Check that the design provides for appropriate systems for fire suppression, notification, and detection.					
B. At 90% of the project design						
1.	Check that the specified fixtures and fittings are to be supplied from a reliable manufacturer.					
2.	Check the specified type of storage water tanks for potable water.					
3.	Check that all pipelines and fittings used for the supply of clean water are lead-free.					
4.	Avoid the specification of any unreinforced PVC at any exposed envelopes to solar radiation.					
5.	Check that the specified elevators are procured from reliable manufacturer and are easy to upgrade.					
6.	Check that the specifications provide for the sealant type that will be used in filling the expansion joints					
7.	Check that the specifications provides for a pressurization system that automatically activates by fire notification/ detection systems.					
Other (Please specify)						

Section V: This section must be completed by the director of HVAC division

A. General Information

Please tick (✓) your answer and fill in the blanks accordingly

1. Respondent Information

Name (Optional)	
Telephone no (Optional)	
Facsimile (Optional)	
E-Mail Address (Optional)	

2. How long have you been working in the maintenance department?

Less than 5 years		5-10 years	
10-20 years		More than 20 years	

3. Are you interested in receiving a summary of the finding of this study?

Yes		No	

4. If yes, Please indicate your address (if you not provide it at the first question)

B. Respondent assessment

B1. Assessment of the most important operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during HVAC design development and review stages

Please rate the degree of importance of each of the identified operation and maintenance problems by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any operation and maintenance problem that can enhance the research and rate it according to the evaluation terms provided above.

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during HVAC design development and review stages		**Assessment**				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Inability to reach and maintenance chillers, cooling towers and condenser due to the location of mechanical plant.					
2.	Signs of biological stains on false ceiling caused by leaky HVAC ducts.					
3.	Moisture condensation on walls and glass due to inappropriate HVAC design temperature.					
4.	Overheating of the building due to shut down of chillers for maintenance or replacement of any parts.					
5.	Overcooling of the building due to temperature difference between the supply and return child water during winter.					
6.	Inadequacy of the HVAC system to provide the required comfort zone temperature.					
7.	Water spillage from HVAC units due to lack of condensation drainage systems.					
8.	Inability to reach and maintain condensation pans location.					
9.	Propagation of foul smells due to lack of provision of exhaust fans in kitchens and toilets.					
10.	Poor indoor air quality that may cause infectious diseases and respiratory illnesses due to insufficient provision of fresh air.					
11.	Static electricity due to insufficient humidification of admitted air to the building.					
12.	Noisy air handling units due to lack of proper insulation.					
Other (Please Specify)						

B2. Assessment of the major concerns and/or details raised by the maintenance manager during HVAC design development and review stages which will have significant impacts on building maintainability in the future

Please rate the degree of importance of each of the identified concerns and/or details by selecting one of the following evaluation terms.

Extremely Important, Very Important, Important, Somewhat Important and Not Important

Please feel free to add any concerns and/or details that can enhance the research and rate it according to the evaluation terms provided above

Major Concerns and/or details raised by the maintenance manager during HVAC design development and review stages		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
A. At 30% of the project design						
1.	Check that the design provides access for reaching cooling towers, chillers, and condensers for maintenance.					
2.	Check that access is provided to air handling unit rooms for ease of maintenance and replacement.					
3.	Check that the cooling towers are located away from the adjacent buildings to eliminate background noise and emissions of mist.					
Other (Please Specify)						
B. At 60% of the project design						
1.	Check that the design provides for air conditioning supply to toilets and ablution areas. These locations should be maintained at negative pressure with properly sized exhaust/extract fans.					
2.	Check that the design provides for more than one chiller, as chillers will operate more efficiently near the peak loads.					
3.	Check that the design provides for a standby chiller that could be operated when other chillers are being serviced.					
4.	Check that the design provides for dividing the HVAC ducting distribution through valves for ease of maintenance.					
5.	Check that the design provides for adequate distance between supply and return diffusers as well as the fresh air intake and exhaust air.					
6.	Check that there is no intermixing of the exhaust air from kitchens and toilets with the fresh air intake from fresh air handling units.					

		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
7.	Check that the design provides for thermal and acoustical insulation for all air handling units and mechanical rooms.					
8.	Check that the design provides for insulating all chilled water pipes to avoid any water leakages as well as condensation problems.					
C. At 90% of the project design						
1.	Check that the design provides for a fan coil unit in the corridors at each floor level.					
2.	Check that the design provides for a fresh air supply through the fan coil unit.					
3.	Check that the design provides for expansion tanks in the chilled water hydronic circuit.					
4.	Check that the specifications provides for using carbon filter in areas where transfer of odor and other contaminants is expected.					
5.	Check that the design provides a complete set of drawings and details for duct distribution, riser diagram and chilled water supply and return ducts.					
6.	Check that the design provides a complete set of drawings and details of the fire/smoke system interlocking with the HVAC system.					
7.	Check that the design provides a complete set of drawings and details for the air handling units, fan coil units, exhaust fans, fire/smoke system and the cooling tower plant.					
Other (Please Specify)						

Part II of questionnaire

This part must be completed by the Administrator of all the last Maintenance Divisions

A. General Information

1- Respondent Information

Name (Optional)	
University Name	
Telephone no (Optional)	
Facsimile (Optional)	
E-Mail Address (Optional)	

2- How long have you been working in the maintenance department?

Less than 5 years		5-10 years	
10-20 years		More than 20 years	

3- On the average, how long have the building in your campus been in operation?

Relatively new buildings (less than 10 years)	
11 years old buildings and above	
Combination of the above	

4- Are you interested in receiving a summary of the finding of this study?

Yes		No	

5- If yes, Please indicate your address (if you not provide it at the first question)

B. Questions on the current practices of the maintenance manager involvement during the design development and review stages

1- Have you been involved or consulted during design development and review stages?

- ☐ Yes, we have been involved (please choose only one):
  - ☐ Often ☐ Sometime ☐ Rarely
- ☐ No, we have not been involved.

2- If yes, how does the involvement occur during design development and review stages?

- ☐ Directly with the integrated design team.
- ☐ Indirectly (Please choose only one)
  - ☐ Through the coordination office between us and the integrated design team.
  - ☐ Through the project management department.
- ☐ Other (please specify) ____.

3- If you have been involved indirectly during design development and review stages, how do you provide feedback to the integrated design team?

- ☐ Through participation in design review meetings.
- ☐ Through commenting on a copy of the design documents sent for review.
- ☐ Other (please specify) ____.

4- If you have been involved during the design development and review stages, did you feel that the projects that you or other reviewed have less operation and maintenance problems than the one which were not reviewed?

O&M Problems	After Reviewed	After Reviewed
	No changes (the Maintenance Department is still facing the same problems)	The volume of the problems faced by the Maintenance Department has decreased by the following percentage (%)
Architectural design problems		
Structural design problems		
Electrical design problems		
Mechanical design problems		
HVAC design problems		
Other (please specify)………………		

5- During which stage of the design process you have been requested to provide feedback to the integrated design team? (check all that applies)

- ☐ Schematic design (30% of project design).
- ☐ Design development (60% of project design).
- ☐ Construction document (90% of project design).
- ☐ Final document, Construction administration phase (100% of project design).
- ☐ Other (please specify) ____

6- How can you ensure that your feedback have been taken into consideration?

- ☐ Through reviewing the resubmitted design documents.
- ☐ Through reviewing the set of the design documents for the next stage.
- ☐ Through reviewing the final design documents at 100% completion.
- ☐ Other (please specify) ____

7- What do you provide feedback on to the integrated design team?

- ☐ Complete set of drawings and specifications for all divisions of work
- ☐ Drawings and specifications for particular divisions of work (check all that applies)
  - ☐ Architecture ☐ Structural ☐ Electrical
  - ☐ Mechanical ☐ HVAC ☐ other (please specify) ____________________
- ☐ Drawings only.

- ☐ Specifications only.
- ☐ Other (please specify) ____

8- If you have involved during design development and review stages, what forms of feedback do you provide to avoid the problems that you are currently experiencing in building maintenance? (Check all that applies).

- ☐ Review of the appropriateness of systems type and performance data.
- ☐ Review of specified materials and/or samples.
- ☐ Review of installation procedures through shop drawings.
- ☐ Review of specified equipment.
- ☐ Review functional design alternatives.
- ☐ Review the structural engineer’s choice of the building structure
- ☐ Other (please specify) ____.

9- On what bases do you provide your feedback to the integrated design team during design development and review stages? (Check all that applies).

- ☐ Based on experience (check all that applies)
  - ☐ Building components which are the most economical to repair and replace.
  - ☐ Building components which are the most difficult to inspect and have access to.
  - ☐ Complaints that your department receive from users
- ☐ Compliance with code requirements (check all that applies)
  - ☐ International Fire Code
  - ☐ International Energy Conservation Code
  - ☐ International Plumbing Code
  - ☐ International Private Sewage Disposal Code
  - ☐ International Mechanical Code
  - ☐ International Property Maintenance Code
  - ☐ International Green Construction Code
  - ☐ International Existing Building Code
- ☐ Post occupancy Evaluation experience
- ☐ Other (please specify) ____.

10- In your opinion, which one of the following project design stages will have a significant reduction of the maintenance works for the buildings in future?

- ☐ Schematic design (30% of project design).
- ☐ Design development (60% of project design).
- ☐ Construction document (90% of project design).
- ☐ Final document, Construction administration phase (100% of project design).

Thank you

APPENDIX – B (SUMMARY OF THE RESPONSES TO THE QUESTIONNAIRE SURVEY)

A summary of the architectural division directors' responses to section I of part I of the questionnaire survey

Operation and maintenance problems that commonly emerge as a consequence of the maintenance manager's lack of involvement during architectural design development and review stages		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Inability to entirely reach and maintain the fenestration due to the architectural form of the building.	6	0	5	1	0
2.	Insufficient availability of specific building materials in the market when replacement of the same is required.	4	4	4	0	0
3.	Inappropriate selection and specification of specific building material for incorporation in the project.	3	5	4	0	0
4.	Propagation of foul odor due the placement of kitchens and toilets in the direction of the prevailing wind.	2	5	0	4	1
5.	Design and placement of large windows in building elevations facing the solar path.	2	3	3	3	1
6.	Difficulty in moving the furniture and equipment within interior spaces due to the limited width and height of doors.	1	6	1	3	1
7.	Wall edges that could chip due to impacts of loads and occupants.	4	6	0	2	0
8.	Specification of low quality tiles that could be heavily stained or degraded due to heavy human traffic and weather condition.	5	4	2	1	0
9.	Signs of stains and seepage due to improper rainwater drainage around windows.	4	6	2	0	0
10.	Visibility of signs of stains and development of moulds due to inadequate means of ventilation (natural or mechanical or a combination of both).	0	5	3	4	0
11.	Signs of stains on the building façade due to the different levels of moisture absorption of building materials.	0	6	4	2	0
12.	Moisture and vapors traveling from wet to dry areas.	2	5	2	3	0
13.	Plaster decay on external wall surface due to dampness.	2	6	3	1	0
14.	Specification of dark color paint as an exterior finish in hot, arid and dusty regions.	0	4	2	3	3
15.	Paint peeling, flaking, blistering, biological attack and efflorescence.	0	4	5	2	1
16	Inability to maintain vertical risers due to the limited areas of the service shafts.	8	4	0	0	0

Major Concerns and/or details raised by the maintenance manager during <u>the architectural design development and review stages</u>		Assessment: Extremely Important	Very Important	Important	Somewhat Important	Not Important
A. At 30% of the project design						
1.	Check that the design considers the orientation of the building and the wind load effect on the building envelops and interior spaces.	0	5	4	3	0
2.	Check that the areas of the windows are appropriate for the prevailing climate and orientation of the building.	1	4	4	3	0
3.	Check that the dimensions of the doors and windows could accommodate movement of furniture.	2	2	6	2	0
4.	Check that the design considers access for the handicapped in terms of provision of suitable parking, emergency egress routes, toilets, ramps for circulation, and suitable elevator panels.	10	2	0	0	0
5.	Check that the design takes into account the ability to accommodate future changes in the layout as demanded by clients.	4	7	0	1	0
6.	Check that all building materials are suitable for the local climate, especially for building envelopes.	1	6	4	1	0
7.	Check that the designer provides intermediate lobby between the outdoor and indoor areas to work as moisture and temperature trapping zone.	1	5	4	2	0
B. At 60% of the project design						
1.	Check that the architectural form of the building provides for ease of cleaning and maintenance of the fenestration.	1	5	4	2	0
2.	Check that basins of agriculture are located away from the facades to avoid dampness	7	2	2	1	0
3..	Check that the design provides the kitchens and bathrooms with windows.	3	1	3	3	2
4.	Check the provision of enough areas for exhaust and service shafts of kitchens and bathroom	3	3	5	1	0
5.	Check that the design provides access for fire fighting and egress routes.	10	2	0	0	0

C. **At 90% of the project design**						
1.	Check that all the materials specified by the design professionals are available at the markets at that time.	5	7	0	0	0
2.	Check that the design documents and specifications provides for exterior doors that swing outward.	4	6	2	0	0
3.	Check that the design of the building envelope provides for ease of replacement of systems and subsystems.	1	4	3	4	0
4.	Check that the specified type and the commercial brand of paint is reliable.	4	2	6	0	0
5.	Check that the specified type of tiles is wear and abrasion resistant.	3	6	3	0	0
6.	Check that the design provides for metal, wood, plastic or rubber walls edges around sharp corners.	4	4	3	1	0
7.	Check that the design and specification provides for a vapor barrier or retarder on the warm side of the wall to avoid internal condensation.	2	3	4	3	0
8.	Check that the design provides a complete set of drawings and details of thermal insulations for walls and roof.	3	7	2	0	0
9.	Check that the design provides for a detailing of waterproofing system to prevent leaks and hence deterioration of steel reinforcement.	2	7	3	0	0
10.	Check that the specified type and the commercial brand of waterproofing are reliable.	1	4	6	1	0

A summary of the Structural division directors' responses to section II of part I of the questionnaire survey

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during structural design development and review stages		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Signs of cracks around columns and beams due to inadequate structural design.	3	1	4	3	1
2.	Cracks in floor slabs, walls, and tiles due to differential settlement.	3	6	1	1	1
3.	Corrosion of steel reinforcement bars due to Insufficient concrete cover.	5	3	2	1	1
4.	Tile deponding, adhesive failure, cracks and fraction at weak points due to expansion and contraction stresses.	3	4	4	0	1
5.	Moisture and dirt infiltration through expansion joints due to inefficient filling materials and sealant.	1	7	3	1	0
6.	Sign of moisture penetration in the basement at beam-wall joints, walls, and ceiling-wall joints due to insufficient waterproofing and insulation.	2	5	1	4	0
7.	Damage to underground pipelines due to the settlement of soil and foundations.	6	2	1	3	0
8.	Plaster crack between concrete brick joints and wall-floor joints.	6	3	1	2	0

Major Concerns and/or details raised by the maintenance manager during structural design development and review stages		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
A. At 30% of the project design						
1.	Check that the design provides for expansion joints when the length of the building exceeds that length specified by the codes	5	5	2	0	0
B. At 60% of the project design						
1.	Check that the results of the soils bearing capacity tests are taken into consideration in the design of the foundation system.	6	4	1	0	1
2.	Check that the design provides for the required strength, thickness, and fire resistance rating of building construction materials	3	5	3	0	1
C. At 90% of the project design						
1.	Check that the design provides for strict specifications for the procurement of concrete.	2	5	4	1	0
2.	Check that the specifications provide for adequate concrete cover for the steel reinforcement as specified by codes.	6	6	0	0	0
3.	Check that the specifications provide for a mesh between concrete brick joints and floor wall joints to avoid any future cracks.	6	5	1	0	0
4.	Check that the specification provide for a full soil compaction (if required) to avoid future settlement.	4	2	5	1	0
5.	Check that the specification provides for appropriate fireproofing and firestopping material in the building.	8	4	0	0	0

A summary of the Electrical division directors' responses to section III of part I of the questionnaire survey

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during the electrical design development and review stages (power, lighting, and communication cables)		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Short circuits due to overload occurrence in plug points.	7	2	3	0	0
2.	Insufficient number and distribution of plugs points..	4	3	4	1	0
3.	Total power cut from one fault.	6	3	0	2	1
4.	Exposed cabling and loose connections	8	3	1	0	0
5.	Exposed Plugs at open and wet areas.	7	3	2	0	0
6.	Flickering and blinking of fluorescent lamps.	4	2	3	3	0
7.	Placement of light switches far away from access points.	4	2	4	2	0
8.	Inadequate provision of the required illumination intensity.	4	3	3	2	0
9.	Inability to reach high ceiling locations for the purpose of changing or cleaning fused light bulbs.	2	4	3	2	1
10.	Inability to reach and maintain the main board of circuit breakers placed in invisible locations.	4	4	3	1	0
11.	Convergence low voltage cabling with high voltage cabling in the same ducts	7	1	2	1	1
12.	Total power and lighting cutoff when fire occurs (Notification systems will not operate in other places)	7	1	2	2	0
13.	Effect of lightning on electrical appliances. (absence of grounding systems)	7	2	2	0	1

Major Concerns and/or details raised by the maintenance manager during the electrical design development and review stages (power, lighting, and communication cables)		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
A. At 60% of the project design						
1.	Check that the main board of circuit breakers is placed in a safe and visible location.	7	4	1	0	0
2.	Check that the design provides for a circuit breaker for each power plug in kitchens as well as for all room light switches.	5	6	1	0	0
3.	Check that the design provides for a sufficient number of luminaries to provide the required illumination intensity.	4	4	4	0	0
4.	Check that the design provides for lighting switches adjacent to access points.	4	5	3	0	0
5.	Check that the design provides for lighting in the elevator shaft.	1	4	6	1	0
6.	Check that the design provides for a sufficient number of power plugs to avoid the use of extension cords.	6	3	3	0	0
7.	Check that the design provides for a fan coil unit - with single point electrical connection box - for power supply and control.	3	3	6	0	0
8.	Check that the designer provides for clear cable management and identification	5	2	4	1	0
9.	Check that the designer provides for communication and internet lines to the all spaces in the building	3	2	7	0	0
10.	Check that the design provides for backup power supply, emergency lighting, and address wiring of fire notification systems, and detection systems	5	3	4	0	0
11.	Check that the provided communication internet lines are away from power and lighting lines	5	2	3	2	0
12.	Check that the design provides for grounding systems.	7	3	2	0	0
B. At 90% of the project design						
1.	Check that the specifications provide fluorescent ballasts that are electronic, high frequency, and of rapid start with no sound.	4	5	3	0	0
2.	Check that the specifications provides for the right diameter of cabling for the lighting system as well as for power plugs.	9	3	0	0	0

A summary of the Mechanical division directors' responses to section IV of part I of the questionnaire survey

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during the mechanical design development and review stages (water supply system, sewage system, vertical transportation, and fire system)		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Inability to reach and maintain pipelines as a result of inappropriate layout of the fitting as well as horizontal runs of pipeline in slabs.	8	3	1	0	0
2.	Inability to distinguish between the pipes servicing the different mechanical systems.	3	6	3	0	0
3.	Water ponds on roofs due to the unavailability of drainage systems.	5	4	2	1	0
4.	Slow sewer drainage due to insufficient diameter of stacks.	6	2	2	1	1
5.	Inability to reach and maintain the sewer lines due to insufficient provision of manholes at corner points.	6	4	2	0	0
6.	Propagation of foul odors due to the absence of ventilation vents.	6	3	3	0	0
7.	Leakage through floor trap due to improper selection of the types of the waterproofing membrane.	2	6	4	0	0
8.	Water leakage due to pipelines penetration through walls or floos.	6	4	1	0	1
9.	Noise and turbulent flow in pipelines due to insufficient diameter.	3	5	3	0	1
10.	Inadequate supply of water due to the insufficient diameter of pipelines and head pressure.	3	3	3	3	0
11.	Complete cut of water supply in the building due to the absence of shut off valves that enable part of supply water to be closed when maintenance is required.	8	3	0	1	0
12.	Corrosion of cast iron pipelines.	6	4	1	1	0
13.	Moulds growth and stains on the façade due to the use of external drainage that penetrates the parapet.	4	6	0	2	0
14.	Fungi and mould growth around the bathtub edges due to the use improper type of sealants.	1	7	3	1	0
15.	Signs of cracks in wall plaster or tiles due to the use of suspended water closets.	3	2	6	1	0
16.	Absence of detection and notification systems at hazardous areas.	11	1	0	0	0
17.	Absence of appropriate fire suppression systems.	7	5	0	0	0

Major Concerns and/or details raised by the maintenance manager during the mechanical design development and review stages (water supply system, sewage system, fire system)		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
A. At 60% of the project design						
1.	Check that there are no pipelines penetrating the walls or the roof.	7	4	1	0	0
2.	Check that the design provides for a complete layout for all the pipelines.	6	4	1	1	0
3.	Check that all the supply pipelines are not running through the slabs.	6	6	0	0	0
4.	Check that there are no horizontal pipelines for supply or drainage run above the false ceiling.	6	4	2	0	0
5.	Check that all pipelines have the right diameter, especially the main riser of water supply and the drainage system.	7	5	0	0	0
6.	Check that the design provides for shutoff valves for each hot and cold riser, as well as for all branches.	11	0	1	0	0
7.	Check that the design provides for manholes for maintaining and cleaning the sewage system, especially at the corners.	6	5	1	0	0
8.	Check that the design provides for two different drainage lines of waste water; one for gray water and one for hand washing in order to store.	4	2	5	1	0
9.	Check that the design provides for sufficient numbers of drainage traps at the roof.	4	4	3	1	0
10.	Check that the design provides for cleanouts at both the ground and roof levels to filter any soil out from the storm water drains.	3	2	4	2	1
11.	Check that the design provides for ventilating stacks to maintain both pressure and siphonage, and avoid foul air entering the space.	6	3	2	1	0
12.	Check that there are no external drainage penetrates any parapets to avoid the development of moulds and stains on the façade.	3	2	3	3	1
13.	Check that the design provides for drains in mechanical plant where spillage might occur.	3	3	4	2	0

14.	Check that the design provides for supply pipelines for fire suppression purposes with appropriate pressure.	5	6	1	0	0
15.	Check that the design provides for means of escape from fire in buildings.	6	1	4	1	0
16.	Check that the design provides for appropriate systems for fire suppression, notification, and detection.	9	3	0	0	0
B. At 90% of the project design						
1.	Check that the specified fixtures and fittings are to be supplied from a reliable manufacturer.	4	4	3	1	0
2.	Check the specified type of storage water tanks for potable water.	3	2	3	4	0
3.	Check that all pipelines and fittings used for the supply of clean water are lead-free.	5	2	3	2	0
4.	Avoid the specification of any unreinforced PVC at any exposed envelopes to solar radiation.	7	2	2	1	0
5.	Check that the specified elevators are procured from reliable manufacturer and are easy to upgrade.	5	4	3	0	0
6.	Check that the specifications provide for the sealant type that will be used in filling the expansion joints	4	8	0	0	0
7.	Check that the specifications provides for a pressurization system that automatically activates by fire notification/ detection systems.	4	5	3	0	0

A summary of the HVAC division directors' responses to section V of part I of the questionnaire survey

Operation and maintenance problems that are attributed to the maintenance manager's lack of involvement during HVAC design development and review stages		Assessment				
		Extremely Important	Very Important	Important	Somewhat Important	Not Important
1.	Inability to reach and maintenance chillers, cooling towers and condenser due to the location of mechanical plant.	6	3	2	0	1
2.	Signs of biological stains on false ceiling caused by leaky HVAC ducts.	4	5	2	1	0
3.	Moisture condensation on walls and glass due to inappropriate HVAC design temperature.	5	3	1	3	0
4.	Overheating of the building due to shut down of chillers for maintenance or replacement of any parts.	6	4	2	0	0
5.	Overcooling of the building due to temperature difference between the supply and return child water during winter.	4	1	6	1	0
6.	Inadequacy of the HVAC system to provide the required comfort zone temperature.	9	1	1	1	0
7.	Water spillage from HVAC units due to lack of condensation drainage systems.	6	4	1	1	0
8.	Inability to reach and maintain condensation pans location.	3	5	4	0	0
9.	Propagation of foul smells due to lack of provision of exhaust fans in kitchens and toilets.	8	2	1	0	1
10.	Poor indoor air quality that may cause infectious diseases and respiratory illnesses due to insufficient provision of fresh air.	7	3	2	0	0
11.	Static electricity due to insufficient humidification of admitted air to the building.	2	3	4	2	1
12.	Noisy air handling units due to lack of proper insulation.	5	4	3	0	0

Major Concerns and/or details raised by the maintenance manager during HVAC design development and review stages		Assessment: Extremely Important	Very Important	Important	Somewhat Important	Not Important
A. At 30% of the project design						
1.	Check that the design provides access for reaching cooling towers, chillers, and condensers for maintenance.	7	2	2	0	1
2.	Check that access is provided to air handling unit rooms for ease of maintenance and replacement.	6	3	2	0	1
3.	Check that the cooling towers are located away from the adjacent buildings to eliminate background noise and emissions of mist.	6	4	1	1	0
B. At 60% of the project design						
1.	Check that the design provides for air conditioning supply to toilets and ablution areas. These locations should be maintained at negative pressure with properly sized exhaust/extract fans.	10	2	0	0	0
2.	Check that the design provides for more than one chiller, as chillers will operate more efficiently near the peak loads.	6	5	1	0	0
3.	Check that the design provides for a standby chiller that could be operated when other chillers are being serviced.	5	5	1	1	0
4.	Check that the design provides for dividing the HVAC ducting distribution through valves for ease of maintenance.	7	4	1	0	0
5.	Check that the design provides for adequate distance between supply and return diffusers as well as the fresh air intake and exhaust air.	8	3	1	0	0
6.	Check that there is no intermixing of the exhaust air from kitchens and toilets with the fresh air intake from fresh air handling units.	10	1	1	0	0
7.	Check that the design provides for thermal and acoustical insulation for all air handling units and mechanical rooms.	5	5	2	0	0
8.	Check that the design provides for insulating all chilled water pipes to avoid any water leakages as well as condensation problems.	8	4	0	0	0

C. At 90% of the project design						
1.	Check that the design provides for a fan coil unit in the corridors at each floor level.	3	6	1	1	1
2.	Check that the design provides for a fresh air supply through the fan coil unit.	4	5	3	0	0
3.	Check that the design provides for expansion tanks in the chilled water hydronic circuit.	4	4	3	1	0
4.	Check that the specifications provides for using carbon filter in areas where transfer of odor and other contaminants is expected.	3	5	3	1	0
5.	Check that the design provides a complete set of drawings and details for duct distribution, riser diagram and chilled water supply and return ducts.	8	3	1	0	0
6.	Check that the design provides a complete set of drawings and details of the fire/smoke system interlocking with the HVAC system.	9	3	0	0	0
7.	Check that the design provides a complete set of drawings and details for the air handling units, fan coil units, exhaust fans, fire/smoke system and the cooling tower plant.	9	2	1	0	0

APPENDIX – C (CRITERIA SCORING MATRIX)

The First Expert Criteria Scoring Matrix

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A*	B*	C*	D*	E*	F*	G*	H*	I*	J*	K*	L*	M*	N*	O*	P*	Q*
A	A-1	C-3	D-3	E-3	F-3	G-3	H-1	I-2	J-2	K-2	L-2	M-2	N-2	O-2	P-2	Q-3	R-1	S-3	T-2	U-3	V-3	W-2	X-3	Y-3	Z-3	A*-3	B*-3	C*-3	D*-3	E*-3	F*-3	G*-3	H*-3	I*-3	J*-3	K*-3	L*-3	M*-3	N*-3	O*-3	P*-3	Q*-3
	B	C-3	D-3	E-3	F-3	G-3	H-3	I-3	J-3	K-3	L-3	M-3	N-3	O-3	P-3	Q-3	R-3	S-3	T-3	U-3	V-3	W-3	X-3	Y-3	Z-3	A*-3	B*-3	C*-3	D*-3	E*-3	F*-3	G*-3	H*-3	I*-3	J*-3	K*-3	L*-3	M*-3	N*-3	O*-3	P*-3	Q*-3
		C	C-D	E-3	F-3	G-3	H-2	I-3	J-3	K-3	L-1	M-3	N-3	O-2	P-2	Q-2	R-1	S-3	T-1	U-1	V-2	W-2	X-2	Y-2	Z-2	A*-2	B*-2	C*-2	D*-2	E*-3	F*-3	G*-3	H*-3	I*-3	J*-2	K*-3	L*-3	M*-2	N*-2	O*-2	P*-2	Q*-3
			D	E-3	F-3	G-3	H-2	I-3	J-2	K-3	L-2	M-3	N-3	O-3	P-3	Q-3	R-2	S-3	T-3	U-3	V-3	W-3	X-3	Y-2	Z-2	A*-2	B*-3	C*-3	D*-3	E*-3	F*-3	G*-3	H*-3	I*-3	J*-3	K*-3	L*-3	M*-3	N*-3	O*-3	P*-3	Q*-3
				E	E-F	E-3	E-3	E-2	E-2	E-2	E-3	E-1	E-1	E-1	E-2	E-Q	E-1	E-S	E-2	E-3	E-2	E-2	E-X	E-Y	E-1	E-1	E-1	E-2	E-1	E-1	E-1	E-1	E-H*	E-I*	E-J*	E-K*	E-L*	E-1	E-1	E-1	E-P*	E-Q*
					F	F-G	F-1	F-I	F-1	F-1	F-1	F-M	F-N	F-O	F-P	Q-1	F-R	S-3	F-1	F-1	F-1	F-1	X-1	F-Y	F-Z	F-A*	F-B*	F-1	F-1	F-1	F-1	F-1	F-H*	F-I*	F-J*	K*-1	L*-1	M*-1	F-N*	F-O*	F-P*	F-Q*
						G	H-1	I-1	J-1	K-1	L-1	M-1	N-1	O-1	G-P	G-Q	G-R	S-3	T-1	U-1	V-1	W-1	X-1	Y-1	Z-2	A*-2	B*-2	C*-2	D*-2	E*-2	F*-2	G*-2	H*-3	I*-3	J*-3	K*-3	L*-3	M*-2	N*-2	O*-1	P*-1	Q*-1
							H	H-I	H-J	H-K	H-L	H-M	H-N	H-O	H-1	H-Q	H-1	S-3	H-1	H-1	H-1	H-1	H-X	H-Y	H-Z	H-A*	B*-1	H-C*	D*-1	E*-1	F*-1	G*-2	H*-3	I*-3	J*-2	K*-3	L*-3	M*-2	N*-2	O*-3	P*-2	Q*_2
								I	J-1	K-1	L-1	I-M	I-N	O-2	P-2	Q-3	R-2	S-3	T-2	U-2	V-2	W-2	X-2	Y-2	Z-3	A*-3	B*-3	C*-3	D*-3	E*-2	F*-3	G*-3	H*-3	I*-3	J*-2	K*-3	L*-3	M*-3	N*-3	O*-3	P*-3	Q*-3
									J	J-K	J-1	J-M	J-N	J-O	J-1	Q-1	J-1	S-3	T-1	U-1	V-1	W-1	X-1	Y-2	Z-2	A*-2	B*-2	C*-3	D*-3	E*-2	F*-3	G*-3	H*-3	I*-3	J*-2	K*-3	L*-3	M*-3	N*-3	O*-3	P*-2	Q*-2
										K	K-3	K-M	K-N	K-O	K-1	K-2	K-1	S-3	T-1	U-1	V-1	W-1	X-1	Y-2	Z-2	A*-2	B*-2	C*-3	D*-2	E*-2	F*-2	G*-2	H*-3	I*-3	J*-2	K*-2	L*-3	M*-3	N*-3	O*-3	P*-3	Q*-3
											L	M-2	N-2	O-2	P-2	Q-3	R-1	S-3	T-1	U-1	V-1	W-1	X-2	Y-2	Z-2	A*-2	B*-2	C*-2	D*-2	E*-2	F*-2	G*-3	H*-3	I*-3	J*-2	K*-3	L*-3	M*-3	N*-3	O*-3	P*-2	Q*-2
												M	N-2	O-2	P-2	Q-3	R-2	S-3	T-2	U-2	V-2	W-3	X-3	Y-3	Z-3	A*-3	B*-3	C*-3	D*-3	E*-3	F*-3	G*-3	H*-3	I*-3	J*-2	K*-3	L*-3	M*-3	N*-2	O*-2	P*-3	Q*-3
													N	N-1	N-2	N-Q	N-1	S-3	T-2	U-2	V-2	W-2	X-3	Y-3	Z-3	A*-3	B*-3	C*-3	D*-3	E*-3	F*-3	G*-3	H*-3	I*-3	J*-2	K*-2	L*-2	M*-1	N*-1	O*-2	P*-2	Q*-2
														O	O-P	O-Q	O-1	S-3	T-2	U-2	V-2	W-2	X-2	Y-2	Z-2	A*-2	B*-3	C*-3	D*-3	E*-3	F*-3	G*-3	H*-3	I*-3	J*-3	K*-3	L*-3	M*-3	N*-2	O*-2	P*-2	Q*-2
															P	Q-3	R-1	S-3	T-1	U-1	V-1	W-1	X-3	Y-3	Z-3	A*-3	B*-3	C*-3	D*-3	E*-3	F*-3	G*-3	H*-3	I*-3	J*-3	K*-3	L*-3	M*-3	N*-3	O*-3	P*-3	Q*-3
																Q	Q-3	S-3	Q-1	Q-1	Q-1	Q-1	X-1	Y-1	Z-1	A*-1	B*-2	C*-2	D*-2	E*-2	F*-3	G*-3	H*-3	I*-3	J*-2	K*-2	L*-3	M*-2	N*-2	O*-2	P*-2	Q*-2
																	R	S-3	T-2	U-2	V-2	W-2	X-3	Y-3	Z-3	A*-3	B*-3	C*-3	D*-3	E*-3	F*-3	G*-3	H*-3	I*-3	J*-3	K*-3	L*-3	M*-3	N*-3	O*-3	P*-3	Q*-3
																		S	S-3	S-3	S-3	S-2	S-2	S-2	S-2	S-2	S-2	S-2	S-2	S-2	S-2	S-G*	S-H*	S-I*	S-1	S-K*	S-L*	S-1	S-1	S-1	S-1	S-1
																			T	T-U	V-1	W-1	X-2	Y-2	Z-2	A*-2	B*-3	C*-3	D*-3	E*-3	F*-2	G*-3	H*-3	I*-3	J*-2	K*-2	L*-3	M*-3	N*-3	O*-3	P*-3	Q*-3
																				U	U-V	U-W	X-1	Y-1	Z-2	A*-2	B*-3	C*-3	D*-3	E*-2	F*-2	G*-3	H*-3	I*-3	J*-3	K*-3	L*-3	M*-2	N*-2	O*-3	P*-3	Q*-2
																					V	V-W	X-1	Y-1	Z-2	A*-2	B*-2	C*-2	D*-2	E*-2	F*-2	G*-3	H*-3	I*-3	J*-2	K*-2	L*-2	M*3	N*-2	O*-3	P*-2	Q*-2
																						W	X-2	Y-2	Z-2	A*-2	B*-2	C*-2	D*-2	E*-2	F*-3	G*-3	H*-3	I*-3	J*-2	K*-2	L*-2	M*2	N*-3	O*-3	P*-2	Q*-2
																							X	X-Y	X-Z	X-1	X-B*	X-C*	X-D*	X-E*	F*-1	G*-3	H*-3	I*-3	J*-1	K*-1	L*-2	M*-1	X-N*	X-O*	X-P*	X-Q*
																								Y	Y-Z	A*-1	B*-1	C*-1	D*-1	E*-1	F*-1	G*-2	H*-3	I*-3	J*-1	K*-1	L*-2	M*-2	N*-2	O*-2	P*-2	Q*-2
																									Z	Z-A*	Z-B*	Z-C*	Z-1	Z-1	Z-F*	G*-1	H*-2	I*-3	J*-1	K*-2	L*-2	Z-M*	Z-N*	Z-O*	Z-P*	Q*-1
																										A*	A*B*	A*-1	A*-1	A*-1	A*-1	G*-1	H*-1	I*-2	A*J*	A*K*	L*-1	A*1	A*-1	A*O*	A*P*	A*Q*
																											B*	C*1	D*1	B*E*	B*-1	B*G*	H*-1	I*-2	B*J*	K*-1	L*-1	M*-1	N*-1	O*-1	P*-1	Q*-1
																												C*	C*D*	C*E*	C*F*	C*G*	C*H*	I*-1	J*-1	K*-1	L*-1	M*-1	N*-1	O*-1	C*P*	C*Q*
																													D*	D*E*	D*F*	D*G*	H*-2	I*-3	J*-2	K*-2	L*-2	M*-2	N*-2	O*-2	P*-3	Q*-2
																														E*	E*F*	G*-1	H*-2	I*-3	J*-1	K*-1	L*-2	M*-2	N*-2	O*-2	P*-2	Q*-2
																															F*	G*-1	H*-2	I*-3	J*-2	K*-2	L*-2	M*-2	N*-2	O*-3	P*-2	Q*-2
																																G*	G*H*	G*I*	G*-1	G*-1	G*L*	G*-1	G*-1	G*O*	G*-1	G*-1
																																	H*	H*I*	H*-3	H*K*	H*L*	H*-2	H*-2	H*-1	H*-2	H*-2
																																		I*	I*J*	I*-1	I*-1	I*-2	I*-2	I*-2	I*-3	I*-3
																																			J*	J*-1	J*-1	J*-2	J*-1	J*O*	J*-1	J*-1
																																				K*	L*-1	K*-1	K*-2	K*-2	K*-2	K*-3
																																					L*	L*-2	L*-3	L*-3	L*-3	L*-2
																																						M*	M*N*	O*-1	M*P*	M*Q*
																																							N*	O*-2	P*-1	Q*-1
																																								O*	O*-1	O*-3
																																									P*	P*Q*
																																										Q*

Importance of Evaluation Terms	
Evalution	**Important**
Major Important	3
Medium Important	2
Minor Important	1
Two letter mean have equal priority	

The Second Expert Criteria Scoring Matrix

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A*	B*	C*	D*	E*	F*	G*	H*	I*	J*	K*	L*	M*	N*	O*	P*	Q*
A	B-2	A-1	D-1	E-3	F-2	G-2	H-2	I-1	A-1	K-1	AL	M-1	A-1	A O	A P	Q-1	A R	S-1	T-3	A U	V-2	W-1	X-1	Y-3	Z-2	A A*	B*-2	A-2	D*-2	A E*	A-3	G*-1	H*-2	I*-3	J*-3	A-2	A L*	M*-1	A N*	O*-2	P*-1	A Q*
	B	B-3	B-2	E-1	F-2	G-2	H-2	I-1	B J	B-1	B-1	B M	B-1	B-1	P-1	Q-1	B-1	S-1	T-2	U-2	V-2	B W	B-2	Y-3	Z-3	B A*	B*-2	B-2	D*-2	B E*	B-2	G*-2	H*-3	I*-3	J*-3	B K*	L*-2	B M*	N*-1	O*-1	P*-1	Q*-1
		C	D-2	E-3	F-2	G-1	C H	I-1	C J	C-1	C-1	M-1	C-1	C-1	C P	Q-2	C R	S-1	T-3	C U	V-3	C-1	C X	Y-3	Z-2	C-1	B*-2	C-1	D*-3	C E*	C-2	G*-2	H*-2	I*-2	J*-3	C K*	L*-1	C M*	N*-1	O*-2	P*-1	Q*-1
			D	E-2	F-2	G-2	D H	D-1	D-2	D-2	D-2	D M	D-1	D-2	D-2	Q-1	D-1	S-1	T-2	U-1	V-3	D W	D-1	Y-3	Z-2	D-2	B*-1	D-1	D*-2	D E*	D-2	G*-2	H*-2	I*-2	J*-3	D K*	L*-1	D-2	N*-1	O*-2	P*-2	Q*-1
				E	E-2	E -G	E-1	E-1	E-2	E-2	E-2	E-1	E-3	E-1	E-2	E-2	E-2	E S	E-1	E-1	E-1	E-2	E-1	Y-1	E-1	E-3	E-1	E-3	E D*	E-1	E-3	E-1	E H*	E I*	E-1	E-2	E-2	E-2	E-1	E O*	E-2	E-2
					F	G-1	F-1	F-1	F-1	F-2	F-2	F-2	F-2	F-1	F-1	F Q	F-1	F S	F T	F-1	F V	F-1	F-2	F Y	F Z	F-2	F B*	F-2	F D*	F E*	F-1	G*-1	H*-1	I*-1	J*-1	F-1	F L*	F-1	F N*	O*-1	F-1	F-1
						G	G-1	G I	G-1	G-1	G-1	G-M	G-1	G-1	G-1	G Q	G-1	G S	T-1	G-1	G V	G-2	G-2	Y-1	G Z	G-3	G B*	G-2	G-D*	G-1	G-1	G G*	G H*	G I*	J*-3	K*-1	G-1	G-1	N*-1	O*-2	G-1	G Q*
							H	I-1	H J	H K	H-2	H M	H-1	H-1	HP	Q-2	H-R	S-1	T-2	U-2	V-2	H W	HX	Y-3	Z-1	H-1	B*-1	H-1	D*-1	H E*	H-1	G*-2	H*-2	I*-2	J*-2	H K*	H L*	M*-1	N*-2	O*-2	H P*	Q*-1
								I	I J	I K	I-1	M-1	I-1	O-1	I-1	Q-1	I R	I S	T-1	U-1	V-2	I-1	I-1	Y-2	Z-1	I-1	I B*	I-1	D*-2	I E*	I-1	G*-2	H*-2	I*-1	J*-2	I K*	L*-1	M*-1	N*-1	O*-1	P*-1	Q*-1
									J	K-1	J-1	M-1	J-1	J O	J-1	Q-2	J-1	S-1	T-2	J U	V-2	W-1	J X	Y-2	Z-1	J-1	B*-2	J-2	D*-2	J E*	J-1	G*-2	H*-2	I*-2	J*-2	K*-1	L*-1	M*-1	N*-3	O*-3	P*-2	Q*-2
										K	K-2	M-2	K-2	K O	K-1	Q-1	KR	S-2	T-2	U-1	V-2	K W	K X	Y-3	Z-2	K-1	B*-1	K C*	D*-2	E*-1	K-1	G*-2	H*-2	I*-2	J*-3	K*-1	L*-1	M*-2	N*-2	O*-2	P*-3	Q*-3
											L	M-2	L N	O-1	P-2	Q-2	R-2	S-2	T-3	U-1	V-3	W-1	L X	Y-3	Z-2	L-1	B*-1	L C*	D*-3	E*-1	L-1	G*-2	H*-1	I*-1	J*-3	K*-1	L*-2	M*-1	N*-2	O*-3	P*-2	Q*-2
												M	M-1	M-1	M-1	Q-1	M-1	M S	T-1	M U	V-2	W-1	M-1	Y-2	Z-1	M-1	B*-1	M-1	D*-2	M E*	M-1	G*-1	H*-2	I*-2	J*-3	M K*	L*-1	M M*	N*-2	O*-3	P*-2	Q*-2
													N	O-1	P-1	Q-2	R-1	S-2	T-2	U-1	V-3	W-1	N X	Y-3	Z-2	N A*	B*-1	N-1	D*-2	E*-1	N-1	G*-2	H*-2	I*-3	J*-3	K*-1	L*-2	M*-1	N*-3	O*-3	P*-2	Q*-2
														O	O P	Q-1	O R	S-1	T-2	O U	V-2	W-1	O X	Y-2	Z-2	O-1	B*-1	O-2	D*-2	E*-1	O F*	G*-1	H*-2	I*-3	J*-3	O K*	L*-1	M*-1	N*-3	O*-3	P*-2	Q*-2
															P	Q-2	P R	S-1	T-2	P U	V-2	P W	P X	Y-2	Z-2	P A*	B*-1	P-1	D*-2	E*-2	P F*	G*-2	H*-2	I*-2	J*-3	K*-1	L*-1	M*-1	N*-3	O*-3	P*-1	Q*-1
																Q	Q-1	Q S	T-1	Q U	V-2	Q W	Q-2	Y-2	Z-1	Q-2	B*-1	Q-3	D*-2	Q E*	Q-3	G*-1	H*-1	I*-1	J*-2	Q-1	Q L*	Q-1	N*-1	O*-2	P*-1	Q Q*
																	R	S-1	T-2	RU	V-3	W-1	R-1	Y-1	Z-1	R A*	B*-1	R C*	D*-2	E*-2	R F*	G*-3	H*-2	I*-3	J*-3	K*-1	L*-2	M*-1	N*-3	O*-3	P*-1	Q*-1
																		S	T-1	S U	V-2	S W	S-1	Y-2	S Z	S-2	B*-1	S-1	D*-1	S E*	S-3	G*-1	H*-1	S I*	J*-2	S-2	S-1	S M*	N*-1	O*-2	S P*	S Q*
																			T	T-1	T V	T-1	T-2	Y-1	T-1	T-3	T-1	T-2	T D*	T E*	T-2	G*-1	H*-1	T I*	J*-2	T-1	T-1	T-1	N*-1	O*-1	T-3	T-2
																				U	V-1	U W	U-1	Y-1	Z-1	U-1	B*-1	C*-1	D*-2	E*-1	U-1	G*-1	H*-1	I*-1	J*-2	U K*	U L*	U M*	N*-1	O*-1	P*-1	Q*-1
																					V	V W	V-2	Y-2	V-2	V-3	V B*	V-2	D*-1	V-1	V-2	V G*	V H*	V I*	J*-2	V-2	V-1	V-2	N*-2	O*-2	V-1	V-2
																						W	W-1	Y-2	Z-2	W-1	B*-2	W B*	D*-1	W E*	W-2	G*-1	H*-1	I*-1	J*-2	W K*	W L*	W-2	N*-2	O*-2	W-2	W-1
																							X	Y-3	Z-2	X-1	B*-2	X C*	D*-2	E*-1	X-2	G*-3	H*-2	I*-3	J*-3	X K*	L*-1	M*-1	N*-3	O*-3	P*-2	Q*-2
																								Y	Y-2	Y-2	Y-1	Y-2	Y D*	Y-1	Y-2	G*-1	Y H*	Y I*	J*-1	Y-2	Y-3	Y-2	Y-1	Y-1	Y-2	Y-2
																									Z	Z-3	B*-1	Y-2	D*-2	E*-1	Z-3	G*-2	H*-2	I*-2	J*-2	Z K*	Z L*	M*-1	N*-2	O*-2	ZP*	ZQ*
																										A*	B*-3	A* C*	D*-3	E*-1	A*-1	G*-2	H*-2	I*-2	J*-2	K*-1	L*-1	A* M*	N*-2	O*-2	P*-2	Q*-2
																											B*	B*-2	B* D*	B*-1	B*-3	G*-1	H*-1	B* I*	J*-1	B*-2	B*-1	B*-2	N*-1	B* O*	B*-1	B*-1
																												C*	D*-3	E*-1	C*-1	G*-2	H*-2	I*-2	J*-2	C*K*	L*-1	M*-1	N*-2	O*-2	P*-2	Q*-2
																													D*	D*-3	D*-3	D*G*	H*-1	D*I*	D*J*	D*-2	D*-2	D*-1	D*N*	D*-2	D*-1	D*-1
																														E*	E*-2	G*-2	H*-2	I*-2	J*-2	E*K*	E*L*	M*-2	N*-2	O*-2	E*P*	E*Q*
																															F*	G*-3	H*-2	I*-3	J*-2	K*-1	L*-1	M*-1	N*-2	O*-2	P*-2	Q*-2
																																G*	H*-2	G*I*	J*-1	G*-2	G*-2	G*-2	N*-2	O*-1	G*-1	G*-1
																																	H*	H*-2	H*-1	H*-3	H*-3	H*-2	H*-1	H*O*	H*-1	H*-1
																																		I*	J*-2	I*-1	I*-1	I*-1	N*-2	O*-3	I*P*	I*Q*
																																			J*	J*-3	J*-3	J*-3	J*N*	J*O*	J*-1	J*-2
																																				K*	L*-2	M*-2	N*-3	O*-3	P*-1	Q*-2
																																					L*	L*-2	N*-2	O*-2	P*-1	Q*-1
																																						M*	N*-3	O*-2	P*-1	M*Q*
																																							N*	N*O*	N*-2	N*-2
																																								O*	O*-2	O*-1
																																									P*	Q*-2
																																										Q*

Importance of Evaluation Terms	
Evalution	**Important**
Major Important	3
Medium Important	2
Minor Important	1
Two letter mean have equal priority	

The Third Expert Criteria Scoring Matrix

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A*	B*	C*	D*	E*	F*	G*	H*	I*	J*	K*	L*	M*	N*	O*	P*	Q*
A	B-3	C-3	D-3	E-3	F-3	G-2	A-2	A-2	A-2	K-2	A-2	M-2	A-2	A-2	P-3	Q-2	A-1	S-3	T-3	U-2	V-3	A-3	X-2	Y-1	Z-1	A-1	B*-3	A-1	D*-1	E*-2	F*-2	G*-3	H*-3	I*-3	J*-3	K*-2	L*-1	A-1	N*-2	O*-2	A-1	Q*-2
	B	C-2	D-3	E-2	F-2	G-2	H-1	I-2	J-2	K-3	B-2	M-2	B-2	O-2	P-3	Q-2	B-1	S-3	T-3	U-3	V-3	B-2	X-1	Y-1	Z-1	B-1	B*-3	B-1	D*-1	E*-2	F*-2	G*-3	H*-3	I*-3	J*-3	K*-2	L*-1	B-2	N*-2	O*-2	P*-1	Q*-2
		C	D-1	E-3	F-2	G-2	H-1	I-2	J-2	K-3	C-2	M-2	C-3	O-1	P-2	Q-3	R-1	S-3	T-3	U-3	V-3	C-2	X-1	Y-2	Z-2	A*-1	B*-2	C-1	D*-1	E*-2	F*-2	G*-3	H*-3	I*-3	J*-3	K*-3	L*-1	C-2	N*-2	O*-2	P*-1	Q*-2
			D	D-1	D-1	D-1	D-1	D-1	D-1	D-1	D-1	D-1	D-1	D-1	D-1	D-1	D-1	S-3	T-3	D-1	D-1	D-1	D-1	D-1	Z-1	A*-1	B*-1	D-1	D-2	D-2	D-2	D-2	H*-3	I*-2	J*-2	K*-2	D-2	D-2	D-1	D-3	D-1	D-2
				E	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-3	E-2	E-2	E-2	E-3	E-2	E-3	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2	E-2
					F	G-2	F-2	F-2	J-2	K-2	L-2	M-3	F-2	O-1	P-3	Q-2	F-2	S-2	T-3	U-2	V-2	F-2	X-1	Y-1	F-3	F-3	B*-2	F-2	F-2	F-1	F*-2	G*-3	H*-3	I*-3	F-2	F-2	F-2	M*-1	N*-1	F-2	F-2	F-2
						G	G-1	I-2	J-2	K-2	G-2	M-3	G-2	O-2	P-3	G-2	G-3	S-3	T-3	U-3	V-2	G-2	G-1	G-1	G-1	A*-1	G-2	G-1	G-1	G-1	F*-1	G*-3	H*-3	I*-3	J*-3	G-2	G-2	M*-1	G-1	O-2	G-2	G-2
							H	I-2	J-2	K-1	L-2	M-2	N-2	O-1	P-3	Q-2	R-2	S-3	T-3	U-3	V-3	W-3	X-2	Y-2	Z-2	A*-1	B*-2	C*-2	D*-2	E*-3	F*-1	G*-2	H*-2	I*-3	J*-2	K*-2	L*-2	M*-1	N*-2	O*-2	P*-2	Q*-2
								I	J-2	K-3	I-2	M-3	I-2	O-2	P-3	Q-3	R-2	S-3	T-3	U-3	V-3	W-2	X-2	Y-2	Z-2	I-2	I-2	C*-2	D*-2	E*-2	F*-2	G*-2	H*-2	I*-2	I-3	I-2	I-1	I-3	I-2	I-3	I-2	I-2
									J	K-2	L-2	M-2	N-2	O-2	P-3	Q-3	R-2	S-3	T-3	U-3	V-3	W-2	X-2	Y-2	J-2	J-2	B*-2	C*-2	J-2	J-2	F*-2	G*-2	H*-2	I*-2	J*-1	K*-1	L*-2	J-2	J-2	J-2	J-2	J-2
										K	K-3	K-1	K-2	O-2	P-3	Q-2	K-1	S-2	T-3	U-2	V-2	K-2	X-2	Y-2	K-2	K-2	K-1	C*-2	K-1	K-1	F*-2	G*-3	H*-3	I*-3	K-1	K-2	K-2	K-3	K-3	K-3	K-3	K-3
											L	M-2	N-2	O-2	P-3	Q-2	R-2	S-3	T-3	U-2	V-3	W-2	X-2	Y-2	Z-2	A*-2	B*-2	C*-2	D*-2	E*-2	F*-2	G*-2	H*-3	I*-3	J*-3	K*-2	L*-2	M*-1	N*-2	O*-2	P*-1	Q*-2
												M	M-2	M-2	P-3	Q-1	M-1	S-2	T-2	U-2	V-2	M-3	X-2	Y-2	Z-1	M-3	B*-2	C*-2	M-2	M-2	M-2	G*-3	H*-3	I*-3	M-2	M-2	M-2	M-2	M-2	M-2	M-2	M-2
													N	O-1	P-3	Q-1	R-1	S-3	T-3	U-2	V-2	W-2	X-2	Y-2	Z-2	A*-2	B*-2	C*-2	D*-2	E*-2	F*-2	G*-2	H*-2	I*-2	J*-2	K*-2	L*-2	M*-2	N*-2	O*-2	P*-2	Q*-2
														O	P-2	O-1	R-2	S-3	T-3	U-2	V-2	O-2	X-2	O-2	O-1	A*-1	B*-2	C*-2	D*-2	E*-2	F*-2	G*-1	H*-2	I*-2	J*-2	K*-1	L*-2	M*-2	N*-2	O*-2	O-1	O-1
															P	P-2	P-2	S-3	T-2	U-1	V-3	W-2	P-2	Y-2	P-1	A*-1	B*-2	C*-2	D*-2	E*-2	F*-2	G*-2	H*-2	I*-2	J*-2	K*-1	L*-2	M*-1	N*-2	P-1	P-2	P-2
																Q	R-1	S-2	T-2	U-1	V-2	W-2	Q-1	Y-2	Q-2	A*-1	B*-2	C*-2	D*-1	E*-2	F*-2	G*-2	H*-1	I*-2	J*-2	Q-1	Q-2	M*-1	N*-2	Q-1	Q-1	Q-2
																	R	R-2	T-1	U-1	V-2	R-1	X-1	Y-1	R-1	R-1	B*-1	R-1	R-1	R-1	R-1	G*-2	H*-1	I*-2	J*-2	K*-2	L*-2	M*-2	R-1	R-2	R-1	R-1
																		S	T-1	U-1	V-2	W-1	X-1	Y-2	Z-1	A*-2	B*-1	C*-2	D*-1	E*-2	F*-2	G*-1	H*-2	I*-2	J*-2	K*-2	L*-2	S-1	S-2	S-2	S-2	S-2
																			T	T-1	T-1	T-2	T-2	T-1	T-1	T-2	T-1	T-2	T-3	T-2	F*-1	G*-2	H*-2	I*-2	J*-2	T-1	T-2	T-3	T-1	T-2	T-1	T-1
																				U	U-1	U-2	U-2	Y-1	Z-1	U-2	U-2	U-2	U-1	U-1	F*-1	G*-2	H*-2	I*-2	J*-1	U-1	U-2	U-2	U-1	U-1	U-1	U-2
																					V	V-1	V-2	V-1	V-2	V-3	V-1	V-1	V-2	V-1	F*-1	G*-2	H*-2	I*-2	J*-1	V-1	V-2	V-1	V-2	V-1	V-1	V-1
																						W	X-1	Y-1	Z-1	W-1	W-2	W-1	W-2	W-1	F*-1	G*-2	H*-2	I*-2	J*-1	W-1	W-2	W-1	W-2	W-2	W-1	W-1
																							X	X-1	Z-1	A*-1	B*-2	X-1	X-1	X-1	F*-1	G*-1	H*-3	I*-3	J*-2	K*-1	X-1	X-2	X-1	X-2	X-1	X-2
																								Y	Y-1	Y-1	B*-1	C*-1	Y-1	Y-2	F*-1	G*-1	H*-2	I*-3	J*-3	Y-1	Y-2	Y-1	Y-1	Y-2	Y-1	Y-2
																									Z	Z-1	Z-2	C*-2	Z-1	Z-1	F*-1	G*-2	H*-2	I*-3	J*-2	Z-1	Z-1	Z-2	Z-2	Z-1	Z-1	Z-1
																										A*	B*-2	C*-2	A*-2	E*-2	F*-3	G*-3	H*-3	I*-3	J*-3	K*-1	L*-2	M*-2	N*-2	O*-2	P*-1	Q*-2
																											B*	B*-2	C*-2	B*-2	F*-3	G*-3	H*-3	I*-3	B*-2	B*-2	B*-2	B*-1	B*-2	B*-1	B*-1	B*-1
																												C*	C*-2	C*-2	F*-3	G*-3	H*-3	I*-3	J*-3	C*-2	C*-2	C*-2	C*-2	C*-2	C*-2	C*-2
																													D*	E*-2	F*-3	G*-3	H*-3	I*-3	D*-2	K*-2	L*-2	M*-1	N*-1	O*-1	P*-1	Q*-1
																														E*	F*-3	G*-3	H*-3	I*-3	J*-3	K*-2	L*-2	M*-2	N*-2	O*-2	P*-2	Q*-2
																															F*	F*-3	H*-3	I*-3	J*-3	F*-3	F*-3	F*-3	F*-3	F*-3	F*-3	F*-3
																																G*	G*-1	I*-3	J*-3	G*-3	G*-2	G*-2	G*-2	G*-3	G*-3	G*-3
																																	H*	H*-3	H*-3	H*-3	H*-3	H*-3	H*-3	H*-3	H*-3	H*-3
																																		I*	I*-3	I*-3	I*-3	I*-3	I*-3	I*-3	I*-3	I*-3
																																			J*	J*-2	J*-2	M*-2	J*-2	J*-2	J*-2	Q*-2
																																				K*	K*-2	K*-2	N*-2	O*-2	K*-2	Q*-2
																																					L*	L*-2	N*-2	O*-2	L*-2	L*-2
																																						M*	N*-2	O*-2	M*-2	Q*-2
																																							N*	N*-2	N*-2	N*-2
																																								O*	P*-1	Q*-1
																																									P*	Q*-1
																																										Q*

Importance of Evaluation Terms	
Evalution	**Important**
Major Important	3
Medium Important	2
Minor Important	1
Two letter mean have equal priority	

APPENDIX – D (MATLAB PROGRAMS FOR CONSISTENCY AND THE RESULTS)

MATLAB Program for Consistency of Data Analysis (The first expert's scoring matrix)

```
%Fadi
clc
clear

O=load('a.txt')                    %O is a 43x43 Matrix of  pair-wise comparison of the first expert


 O1=triu(O,1)
 O2=O1'
 O3=O2+triu(O,0)
 O4=1./O3
 O=tril(O4,-1)+triu(O,0)          %To get the total matrix O from the Upper triangular.

M=10;
  n=0;
while(M>.05)                        % when M >0.05 the loop will continue
    n=n+1;
   A=O^(n+1)                        % (A) Matrix to the power (n+1)
   B=sum(A,2);                      % Summation of row elements
   C=sum(B);                        % Eigen value of A
   D=B/C                            % Eigenvector of A
   E=[D]                            % Display the Eigenvector for A

  F=O^(n+2)                         %( F) Matrix to the power (n+2)
  G=sum(F,2);                       % Summation of row elements
  H=sum(G);                         % Eigen value of F
  I=G/H                             % Eigenvector of F
  J=[I]                             % Display the Eigenvector for A
  K=D-I                             % Subtraction of A& F to get consistency values
  L=[K]                             % Display the Comparison of Eigenvector
  M=sum(abs(K))                     % Summation of all the elements

end
N=[D I K]                           % Display the final iteration
n                                   % No. of iteration
```

Results of Consistency Analysis ((The first expert's scoring matrix)

N = D	- I	= K
0.0083	0.0085	-0.0001
0.0074	0.0076	-0.0002
0.0108	0.0110	-0.0002
0.0088	0.0091	-0.0002
0.0287	0.0289	-0.0003
0.0226	0.0230	-0.0004
0.0159	0.0160	-0.0001
0.0166	0.0167	-0.0001
0.0120	0.0121	-0.0002
0.0141	0.0142	-0.0001
0.0156	0.0157	-0.0000
0.0123	0.0125	-0.0001
0.0123	0.0125	-0.0002
0.0152	0.0153	-0.0001
0.0141	0.0142	-0.0001
0.0132	0.0133	-0.0000
0.0193	0.0193	-0.0000
0.0121	0.0122	-0.0001
0.0400	0.0400	-0.0000
0.0146	0.0146	0.0000
0.0154	0.0154	0.0000
0.0167	0.0167	-0.0000
0.0165	0.0165	-0.0000
0.0245	0.0245	0.0000
0.0234	0.0233	0.0001
0.0267	0.0266	0.0001
0.0281	0.0281	0.0000
0.0298	0.0297	0.0001
0.0299	0.0299	0.0001
0.0262	0.0259	0.0003
0.0267	0.0264	0.0002
0.0266	0.0263	0.0003
0.0342	0.0342	0.0001
0.0423	0.0423	0.0000
0.0466	0.0466	0.0000
0.0331	0.0330	0.0001
0.0374	0.0374	-0.0000
0.0420	0.0420	-0.0001
0.0323	0.0321	0.0003
0.0312	0.0309	0.0003
0.0347	0.0345	0.0002
0.0316	0.0313	0.0003
0.0301	0.0298	0.0002

n = 1

MATLAB Program for Consistency of Data Analysis (The second expert's scoring matrix)

```
%Fadi
clc
clear

O=load('b.txt')                    %O is a 43x43 Matrix of  pair-wise comparison of the second expert


 O1=triu(O,1)
 O2=O1'
 O3=O2+triu(O,0)
 O4=1./O3
 O=tril(O4,-1)+triu(O,0)           %To get the total matrix O from the Upper triangular.

M=10;
  n=0;
while(M>.05)                       % when M >0.05 the loop will continue
    n=n+1;
   A=O^(n+1)                       % (A) Matrix to the power (n+1)
   B=sum(A,2);                     % Summation of row elements
   C=sum(B);                       % Eigen value of A
   D=B/C                           % Eigenvector of A
   E=[D]                           % Display the Eigenvector for A

  F=O^(n+2)                        %( F) Matrix to the power (n+2)
  G=sum(F,2);                      % Summation of row elements
  H=sum(G);                        % Eigen value of F
  I=G/H                            % Eigenvector of F
  J=[I]                            % Display the Eigenvector for A
  K=D-I                            % Subtraction of A& F to get consistency values
  L=[K]                            % Display the Comparison of Eigenvector
  M=sum(abs(K))                    % Summation of all the elements

end
N=[D I K]                          % Display the final iteration
n                                  % No. of iteration
```

Results of Consistency Analysis ((The second expert's scoring matrix)

N = D	- I	= K
0.0173	0.0173	-0.0000
0.0195	0.0195	0.0000
0.0162	0.0163	-0.0001
0.0199	0.0199	-0.0000
0.0325	0.0325	0.0000
0.0260	0.0259	0.0000
0.0248	0.0248	0.0000
0.0188	0.0188	-0.0000
0.0198	0.0198	-0.0000
0.0167	0.0168	-0.0000
0.0161	0.0162	-0.0000
0.0147	0.0148	-0.0001
0.0186	0.0186	-0.0000
0.0150	0.0150	-0.0001
0.0174	0.0175	-0.0001
0.0169	0.0169	-0.0001
0.0240	0.0240	-0.0000
0.0175	0.0175	-0.0000
0.0228	0.0229	-0.0000
0.0307	0.0306	0.0001
0.0222	0.0222	-0.0000
0.0324	0.0323	0.0001
0.0205	0.0205	-0.0000
0.0157	0.0157	-0.0000
0.0376	0.0375	0.0001
0.0242	0.0241	0.0000
0.0148	0.0148	-0.0000
0.0270	0.0270	-0.0000
0.0163	0.0163	0.0000
0.0344	0.0344	-0.0000
0.0202	0.0202	-0.0000
0.0140	0.0140	-0.0001
0.0303	0.0303	0.0000
0.0335	0.0335	0.0001
0.0300	0.0300	0.0001
0.0427	0.0427	0.0000
0.0166	0.0167	-0.0000
0.0209	0.0209	-0.0000
0.0189	0.0190	-0.0000
0.0359	0.0359	0.0001
0.0380	0.0379	0.0001
0.0240	0.0240	0.0000
0.0246	0.0246	-0.0000

n = 1

MATLAB Program for Consistency of Data Analysis (The third expert's scoring matrix)

```
%Fadi
clc
clear

O=load('c.txt')                    %O is a 43x43 Matrix of  pair-wise comparison of the third expert


 O1=triu(O,1)
 O2=O1'
 O3=O2+triu(O,0)
 O4=1./O3
 O=tril(O4,-1)+triu(O,0)          %To get the total matrix O from the Upper triangular.

M=10;
  n=0;
while(M>.05)                        % when M >0.05 the loop will continue
    n=n+1;
   A=O^(n+1)                        % (A) Matrix to the power (n+1)
   B=sum(A,2);                      % Summation of row elements
   C=sum(B);                        % Eigen value of A
   D=B/C                            % Eigenvector of A
   E=[D]                            % Display the Eigenvector for A

  F=O^(n+2)                         %( F) Matrix to the power (n+2)
  G=sum(F,2);                       % Summation of row elements
  H=sum(G);                         % Eigen value of F
  I=G/H                             % Eigenvector of F
  J=[I]                             % Display the Eigenvector for A
  K=D-I                             % Subtraction of A& F to get consistency values
  L=[K]                             % Display the Comparison of Eigenvector
  M=sum(abs(K))                     % Summation of all the elements

end
N=[D I K]                           % Display the final iteration
n                                   % No. of iteration
```

Results of Consistency Analysis ((The third expert's scoring matrix)

N = D	- I	= K
0.0144	0.0145	-0.0001
0.0136	0.0137	-0.0001
0.0142	0.0143	-0.0001
0.0233	0.0233	-0.0000
0.0414	0.0416	-0.0002
0.0222	0.0223	-0.0001
0.0203	0.0203	-0.0000
0.0113	0.0114	-0.0001
0.0193	0.0194	-0.0001
0.0188	0.0188	0.0000
0.0251	0.0250	0.0001
0.0122	0.0122	-0.0001
0.0269	0.0268	0.0000
0.0121	0.0122	-0.0001
0.0173	0.0174	-0.0000
0.0257	0.0256	0.0001
0.0211	0.0210	0.0001
0.0198	0.0199	-0.0001
0.0286	0.0285	0.0001
0.0335	0.0334	0.0001
0.0288	0.0287	0.0001
0.0308	0.0307	0.0001
0.0210	0.0211	-0.0001
0.0213	0.0213	0.0000
0.0244	0.0243	0.0001
0.0194	0.0194	-0.0001
0.0146	0.0146	-0.0001
0.0250	0.0249	0.0001
0.0248	0.0247	0.0001
0.0179	0.0180	-0.0001
0.0190	0.0190	0.0000
0.0342	0.0340	0.0002
0.0382	0.0379	0.0003
0.0483	0.0483	-0.0000
0.0488	0.0487	0.0000
0.0317	0.0317	-0.0000
0.0209	0.0209	-0.0000
0.0186	0.0187	-0.0001
0.0164	0.0166	-0.0001
0.0219	0.0219	0.0000
0.0197	0.0197	0.0000
0.0159	0.0161	-0.0001
0.173	0.0174	-0.0001

n = 1

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